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LEVEL II

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TRACOR

TECHNICAL NOTE

SOME COMPUTED EFFECTS OF ASSUMED INOPERATIVE TRANSDUCER STAVES ON BEAM FORMATION AND SSI PERFORMANCE IN THE AN/SQS-26 (XN-2) SONAR EQUIPMENT (U)

Prepared for

The Bureau of Ships
Code 688E

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Contract NObsr-91039
Project Serial Number SS041-001, Task 8100

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(6) SOME COMPUTED EFFECTS OF ASSUMED INOPERATIVE TRANSDUCER STAVES ON BEAM FORMATION AND SSI PERFORMANCE IN THE AN/SQS-26 (XN-2) SONAR EQUIPMENT.

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This technical note contains partial results of a series of studies performed for the SOFIX Program management.

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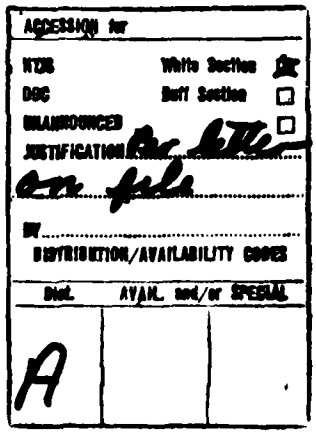
TABLE OF CONTENTS

		Page
I.	INTRODUCTION	1
II.	COMPUTATIONS	2
III.	HORIZONTAL BEAM PATTERN EFFECTS	2
IV.	SSI BEARING ERROR	6
V.	PHASE DELAY CONSIDERATIONS	6
VI.	CONCLUSIONS	11
REFERENCES		13
APPENDIX - HORIZONTAL BEAM PATTERNS AND SSI PHASE PLOTS		14



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TECHNICAL NOTE

SOME COMPUTED EFFECTS OF ASSUMED INOPERATIVE TRANSDUCER STAVES ON BEAM FORMATION AND SSI PERFORMANCE IN THE AN/SQS-26 (XN-2) SONAR EQUIPMENT (U)

I. INTRODUCTION

This technical note is a supplement to a previous TRACOR technical memorandum on redundancy[1], which contained discussions of the effects of inoperative transducer elements, power amplifiers and preamplifiers on beam patterns and SSI bearing error, as well as an analytical treatment of the effects of noise on SSI bearing error. Only random inoperative elements and inoperative horizontal layers of elements were considered in that investigation.

The present investigation was made to determine some of the effects of inoperative post amplifiers, or transducer staves, on horizontal beam patterns and SSI bearing error. The study was limited to those cases which would cause relatively large changes in the parameters of interest. Using the results of a previous study[2] concerning the effects of inoperative staves on AN/SQS-23 performance, it was decided that if at least 25% of the AN/SQS-26 staves were assumed to be inoperative, significant changes in the computed horizontal beam pattern would result.

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[1] "Some Redundancy Effects on AN/SQS-26 Performance (U)," Confidential Technical Memorandum, 9 September 1963, TRACOR, Inc., Contract NObsr-89265. TRACOR Document Number 63-233-C. (This is reference 1 in the list of References).

[2] "Some Effects of Inoperative Transducer Elements on AN/SQS-23 Operation", Confidential Final Report, 3 July 1962, TRACOR, Inc., Contract NObsr-85185, Problem 10. (This is reference 2 in the list of References)

II. COMPUTATIONS

The computations were limited to the receive mode of operation (6^{o} horizontal beam width at the 3 db down points) using a frequency of 3.5 kc and a tilt angle of 0^{o}. Extrapolations of the results to other tilt angles can be made with reasonable accuracy. The computer program used in the present investigation was one of the programs previously developed for generating the beam patterns in the redundancy study.

Computations were made for eleven arrays assuming from six to twelve inoperative staves out of a total of 24. Of these eleven arrays, six had inoperative staves in random locations in the array while the other five assumed that the inoperative staves were grouped in various locations in the array. Of the six arrays with randomly located inoperative staves, there were two arrays each with six, eight and twelve inoperative staves. In the five "ordered" arrays, six adjacent staves were assumed to be inoperative and the location of this inoperative group of staves was varied from the array center to one end of the array to simulate the effects on adjacent fixed horizontal beams.

III. HORIZONTAL BEAM PATTERN EFFECTS

The changes in horizontal receiving directivity index and side lobe level computed for arrays assuming inoperative staves are presented in Table I. As might be expected, the magnitudes of the computed changes are, in general, commensurate with the number of randomly located inoperative staves. The changes computed here for arrays with inoperative staves far exceed those computed in the previous redundancy study[3] for the same percentage of randomly located inoperative elements.

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[3] See reference 1

TABLE I. CHANGES IN HORIZONTAL RECEIVING DIRECTIVITY INDEX, SIDE LOBE LEVEL AND SSI BEARING ERROR COMPUTED FOR AN/SQS-26 (XN-2) ARRAYS WITH ASSUMED INOPERATIVE STAVES

Array No.	No. of Active Staves	Method of Selection	Horizontal Receiving Directivity Index (Δ_R)	Change in Δ_R	Side Lobe Level	Change in S.L.L.	SSI	
							Ratio of Phase Diff. Bearing Angle	Bearing Error*
1	24	All Active	-17.1 db	--	-18.5 db	--	26.8	0.00 deg
64	18	Random	-16.1	-1.0 db	-14.0	4.5 db	24.2	0.05
65	18	Random	-15.7	-1.4	-10.5	8.0	26.7	0.12
66	16	Random	-15.6	-1.5	-12.5	6.0	24.5	-0.30
67	16	Random	-15.5	-1.6	-10.9	8.5	28.0	0.36
68	12	Random	-14.4	-2.7	- 9.5	9.0	25.2	0.16
69	12	Random	-13.6	-3.5	- 9.5	9.0	25.9	-0.12
70	18	Ordered	-15.7	-1.4	- 4.5	14.0	38.0	0.00
71	18	Ordered	-15.5	-1.6	- 2.8	15.7	38.0	0.49
72	18	Ordered	-15.4	-1.7	- 2.5	16.0	35.6	0.52
73	18	Ordered	-15.6	-1.5	-11.0	7.5	22.9	-0.17
74	18	Ordered	-16.5	-0.6	-13.0	5.5	22.4	-0.61

*The sign of the bearing error indicates the direction (right or left) of the error. Of course, for a mirror image array, the sign of the error would change.

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For the arrays in which six adjacent staves were assumed to be inoperative, the computed side lobe level increased markedly from the levels computed for a complete array. The largest side lobe increases, ranging from 14 to 16 db, were for the three arrays with the assumed inoperative staves relatively near the array center. This means that the side lobes would be down from the main lobe only 2.5 to 4.5 db in these cases. However the two arrays in which the inoperative staves were assumed to be near the edge of the array exhibited smaller side lobe increases of 5.5 and 7.5 db; these increases are about the same as those computed for arrays with six randomly located inoperative staves. Only slightly larger changes in side lobe level were computed for arrays with eight and twelve randomly located inoperative staves.

The computed values of receiving directivity index for the various arrays were generally commensurate with the number of operative staves in the array; the directivity index decreases as the number of operative staves decreases. This general relationship held even for the "ordered" cases in which six adjacent staves were assumed to be inoperative. The computed changes in directivity index for the eleven arrays ranged from 0.6 db to 3.5 db.

The probability of occurrence of six adjacent inoperative staves in an array is very small provided that the post amplifiers are completely independent of each other. However if they have a common power supply which could cause failure to occur in groups, the probability of occurrence is significantly increased. If this or a similar situation exists, care should be taken to connect the circuits so that the post amplifiers associated with a common device (such as a power supply) would be randomly located in the array.

Computed horizontal beam patterns for the eleven arrays with inoperative staves are included in the Appendix of this technical

note. The array numbers shown in Table I and on the beam patterns are for identification purposes only.

The major effect of inoperative staves on receiving fixed beam coverage (B-Scan) is in the side lobe structure shown in the patterns. The significant increases in side lobe level computed for some of the arrays assumed for this study could cause a target indication at a false bearing. Examples of this rather radical computed side lobe structure can be seen in arrays 70 through 73. These are relatively improbable cases in which six adjacent staves were assumed to be inoperative near the array center.

In the B-Scan, the adjacent fixed horizontal beams are 5^{o} apart, so that the normal overlap point is about -1.5 db for all-elements-active arrays (using XN-2 phasing). For the arrays computed in the present limited study, the change in the beam overlap is relatively small, provided that the gain at each beam peak is adjusted to a common value to account for loss in sensitivity caused by inoperative staves. The change in overlap point is generally less than 1 db; however, in the worst case computed, the overlap point would be about -4 db, which is 2.5 db below the normal beam overlap point.

The same general results apply to the 12 beams of the A-Scan. With the 10^{o} beam spacing, the overlap point is normally at about -8 db. For the cases computed here, the changes in overlap point would be less than 3 db, which is comparable with that for the same equivalent number of random inoperative elements.[4]

The effects of these computed decreases in fixed beam overlap points on the sonar equipment's horizontal coverage are not immediately obvious, but are known to be greater than the computed values above would indicate. These effects should be assessed in terms of the resulting decrease in signal-to-noise ratio and should include the subsequent signal processing effects.

[4]See reference 1.

This assessment will be carried out in a separate subsequent study.

IV. SSI BEARING ERROR

The computed SSI bearing errors (using XN-2 phasing and shading) due to inoperative staves are shown in Table I along with the ratio of electrical phase difference to SSI bearing. The SSI phase plots and array diagrams are contained in the Appendix. As might be expected, the largest bearing errors occur for the cases in which six adjacent staves are assumed to be inoperative. The largest bearing error (-0.61°) was computed for Array 74, which is the situation in which six adjacent inoperative staves were located at one end of the array (See section V below). The case for which the six adjacent inoperative staves were in the exact center of the array (three in each array half) yielded zero bearing error, as would be expected.

For the random inoperative stave cases, the greatest bearing error (0.36°) was for Array 67, which assumed eight inoperative staves. Most of the inoperative staves were located on one side of the array in this particular example.

There is quite a wide variation in the ratio of electrical phase difference to SSI bearing angle for the various arrays, as is shown in Table I. However, this variation is relatively unimportant since the SSI automatically tracks the target after the first echo is displayed on the SSI.

V. PHASE DELAY CONSIDERATIONS

The phase delays used in computing the patterns and SSI phase plots for the redundancy technical memorandum,[5] the tolerance

[5] See reference 1.

technical memorandum[6] and this technical note were obtained from USNUSL and are the values used in the AN/SQS-26 (XN-2) sonar equipment. The XN-2 horizontal phase delays are shown in Table II; these values apparently do not phase the transducer to a straight line at zero bearing. Calculated straight-line horizontal phase delays for the AN/SQS-26 are also shown in Table II for comparison.

Mr. Baline of USNUSL indicated orally that the XN-2 phasings were deliberately not straight-line, but that corrections could probably be made in the XN-2 equipments to yield straight-line phasing.

The effect of inoperative staves or elements on SSI bearing error is directly related to the horizontal phasing of the array. If the array is phased to a straight line on-axis, then no systematic SSI bearing error will exist at the null as a result of inoperative elements or staves. That is, in the absence of noise, the phase of the received signal is independent of the number of contributing elements and staves provided that at least one element is operative in each array-half (see discussion of the effect of S/N on bearing error below). If a stave signal of φ_1 is added to another stave signal of phase φ_1, the resulting signal also has a phase φ_1; therefore, as signals with the same phase are added, the phase remains unchanged. Hence in the absence of noise, the resultant phase is the same for each array-half if the array is phased to a straight line.

The array may not be phased to a straight line, however, due either to variations (within specified tolerances) in the phase associated with the transducer elements or preamplifiers,

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[6] "Some Computed Effects of Phase and Amplitude Tolerances of Transducer Elements and Preamplifiers on Beam Formation and SSI Performance in the AN/SQS-26 Sonar Equipment (U)," Confidential Technical Memorandum, 25 September 1963, TRACOR, Inc., Contract NObsr-89265, TRACOR Document Number 63-242-C. (This is reference 3 in the List of References).

TABLE II. HORIZONTAL PHASE DELAYS FOR AN/SQS-26 (XN-2) AND AS COMPUTED FOR A STRAIGHT LINE AT ZERO BEARING

Stave No.	XN-2 Phase Delays (deg.)	Phase Delays Computed for a Straight Line (deg.)	Difference (deg.)
1	0	0	0
2	17.5	17.0	0.5
3	52	48	4
4	104	94	10
5	172	157	15
6	256	237	19
7	356	327	29
8	470	432	38
9	600	549	51
10	740	676	64
11	890	819	71
12	1040	968	72

or to intentional departure from straight-line phasing. In the case of inherent phase shifts in the elements and preamplifiers, a small SSI bearing error will probably exist at the null, even when all elements are operative. For that case, the phase-compensated element signals for a plane sound wave travelling in the direction of the array axis would not all have the same phase; thus the resulting phase for each array-half would, with high probability, not be exactly the same. However, in the limited study[7] made on the effects of phase tolerances it was shown that the SSI error resulting from the presently specified phase tolerance ($\pm 9^{o}$) is quite small and is insignificant operationally. Of course, reasonable care must be taken in assembly of the transducer to ensure a randomness of the location of elements with plus and minus variations,[8] since a random distribution is required to keep the error small.

In case the array is not phased to a straight line, which is the situation for the arrays computed for this report, inoperative elements or staves would produce an SSI bearing error, except for arrays in which the assumed inoperative elements or staves are located symmetrically about the array center. This is true because each of the phase-compensated stave signal phases in one array-half would be different for a plane wave travelling in the direction of the array axis. Thus, if one or more staves in an array-half were inoperative, the phase of that array-half would be changed, so that the phases of the two array-halves would no longer be alike. This would result in a non-zero phase difference at zero SSI bearing.

The magnitude of the bearing error is related to the number and location of the inoperative elements or staves as well as the

[7] See reference 3.

[8] See reference 3, "Note" on p. 22.

amount of departure from straight-line phasing. For example, if the phase delays are 5 to 10% different from those for straight-line phasing, errors due to this effect would be at least an order of magnitude greater than those due to presently specified phase tolerances on the elements and preamplifiers.

As stated above, the XN-2 horizontal phase delays shown in Table II were used in computing all of the horizontal receiving beam patterns and SSI phase plots contained in the redundancy technical memorandum,[9] the tolerance technical memorandum,[10] and this technical note. Therefore, these patterns are valid only for this non-straight-line phasing. In contrast, if straight-line phasing is used, the systematic bearing error due to inoperative elements or staves would be zero in the absence of noise. However, in the presence of noise, the reduction in receiving directivity index correspondent with the reduced number of operative elements results in a smaller effective signal-to-noise ratio at the input to the SSI. As has previously been shown,[11,12] rms bearing error increases as signal-to-noise ratio decreases. Therefore, for straight-line phasing, the only bearing errors resulting from inoperative elements or staves are caused indirectly by the presence of noise.

The effect due to changing the phasing to straight-line is quite noticeable in the computed beam patterns, but is probably of no operational significance. One effect of straight-line phasing is to produce a sharp null between the main lobe and the

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[9] See reference 1.

[10] See reference 3.

[11] See reference 1, Figure 18.

[12] "The Effect of Echo Length on SSI Bearing Error in the Presence of Noise (U)," Confidential Technical Note, 25 October 1963, TRACOR, Inc., Contract NObsr-89265, TRACOR Document Number 63-263-C, Figure 2. (This is reference 4 in the List of References).

first side lobe, which was not observed when XN-2 phasing values were used. The effects of inoperative elements and staves on the various beam pattern parameters probably would be very similar for XN-2 phasing and straight-line phasing. However, if the patterns are to be used for a definitive study, they should be recomputed using phasing values corresponding to those actually used in the equipment.

VI. CONCLUSIONS

1. The computed changes in receiving directivity index and side lobe level resulting from randomly located inoperative staves are much greater than the computed changes resulting from a comparable percentage of randomly located inoperative elements.

2. In the cases where six adjacent staves were assumed to be inoperative near the array center, the computed increases in side lobe level were very pronounced - 14 to 16 db. However, for the same arrays, a change of only about 1.5 db in directivity index was computed, which is comparable with that for arrays assuming six randomly located inoperative staves.

3. The probability of occurrence of six adjacent inoperative staves would be very small unless they have a common circuit, such as a power supply. In this event, care should be taken to ensure random connections where possible.

4. SSI bearing errors as large as 0.6° were computed for cases in which six adjacent staves were assumed inoperative, using XN-2 phasing. Smaller errors were computed for the cases with randomly located inoperative staves.

5. When straight-line phasing is employed, there is no systematic SSI bearing error due to inoperative staves.

However, the reduction in receiving directivity index caused by the loss of a stave or staves, with the attendant reduction in SSI input signal-to-noise ratio, can result in an increased rms bearing error.

6. The effect of inoperative staves on receiving fixed beam horizontal coverage, based on the present limited study, is in the side lobe structure. If actual situations existed, such as those assumed here, it is quite conceivable that target indications at false bearings would be observed. However, the effects of reduced signal-to-noise ratio and signal processing on horizontal fixed beam coverage need further study.

REFERENCES

1. "Some Redundancy Effects on AN/SQS-26 Performance (U)," Confidential Technical Memorandum, 9 September 1963, TRACOR, Inc., Contract NObsr-89265. TRACOR Document Number 63-233-C.

2. "Some Effects of Inoperative Transducer Elements on AN/SQS-23 Operation (U)," Confidential Final Report, 3 July 1962, TRACOR, Inc., Contract NObsr-85185, Problem 10.

3. "Some Computed Effects of Phase and Amplitude Tolerances of Transducer Elements and Preamplifiers on Beam Formation and SSI Performance in the AN/SQS-26 Sonar Equipment (U)," Confidential Technical Memorandum, 25 September 1963, TRACOR, Inc., Contract NObsr-89265, TRACOR Document Number 63-242-C.

4. "The Effect of Echo Length on SSI Bearing Error in the Presence of Noise (U)," Confidential Technical Note, 25 October 1963, TRACOR, Inc., Contract NObsr-89265, TRACOR Document Number 63-263-C, Figure 2.

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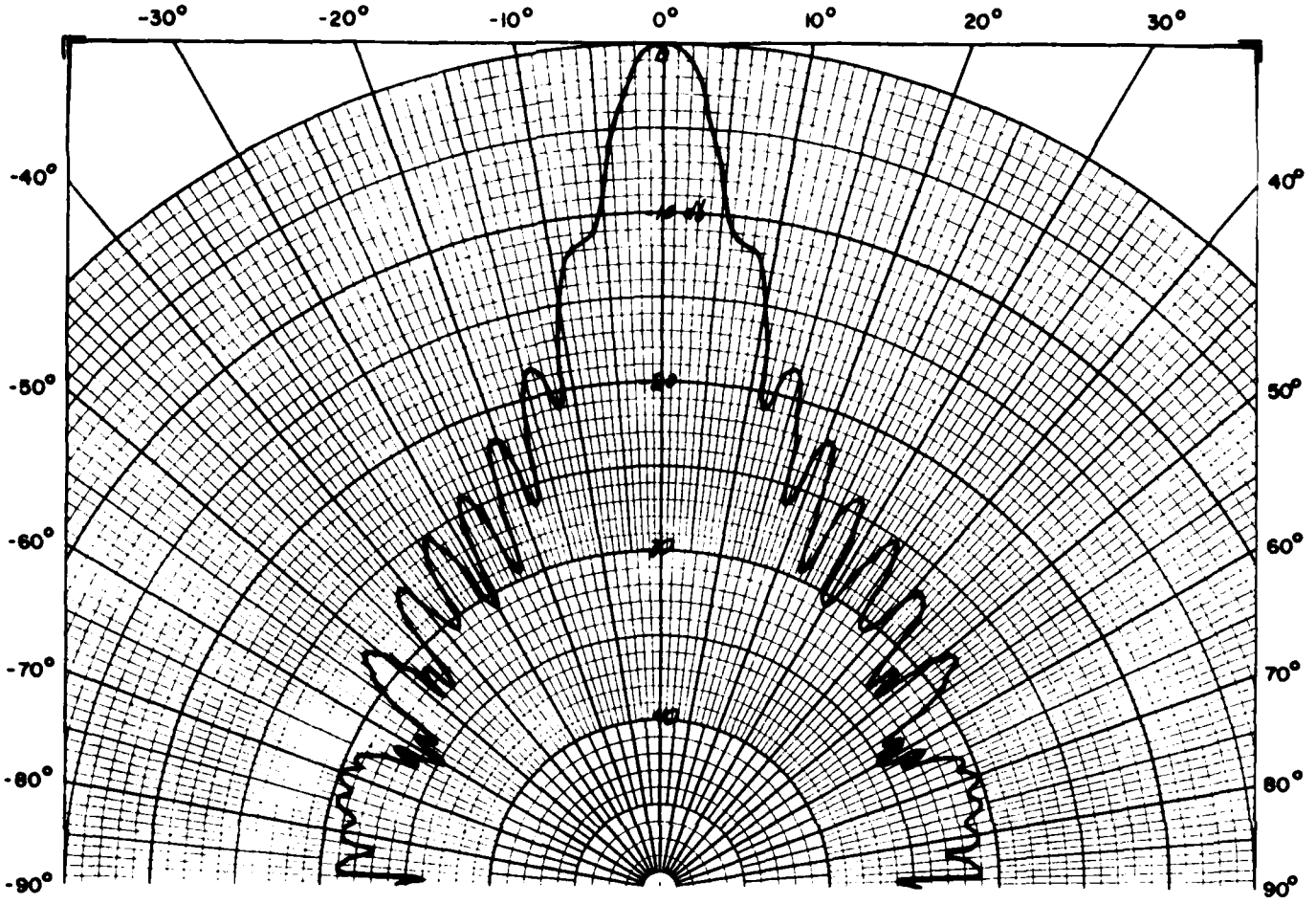
APPENDIX

HORIZONTAL BEAM PATTERNS

and

SSI PHASE PLOTS



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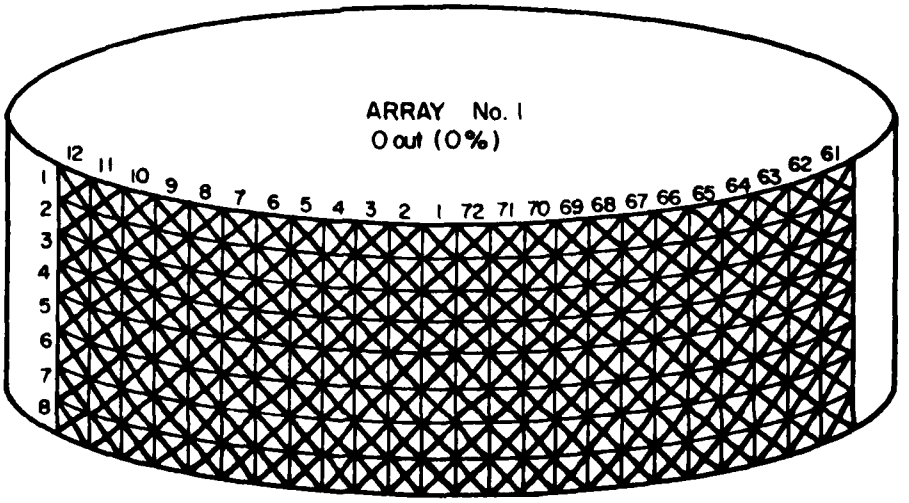
0° TILT ANGLE



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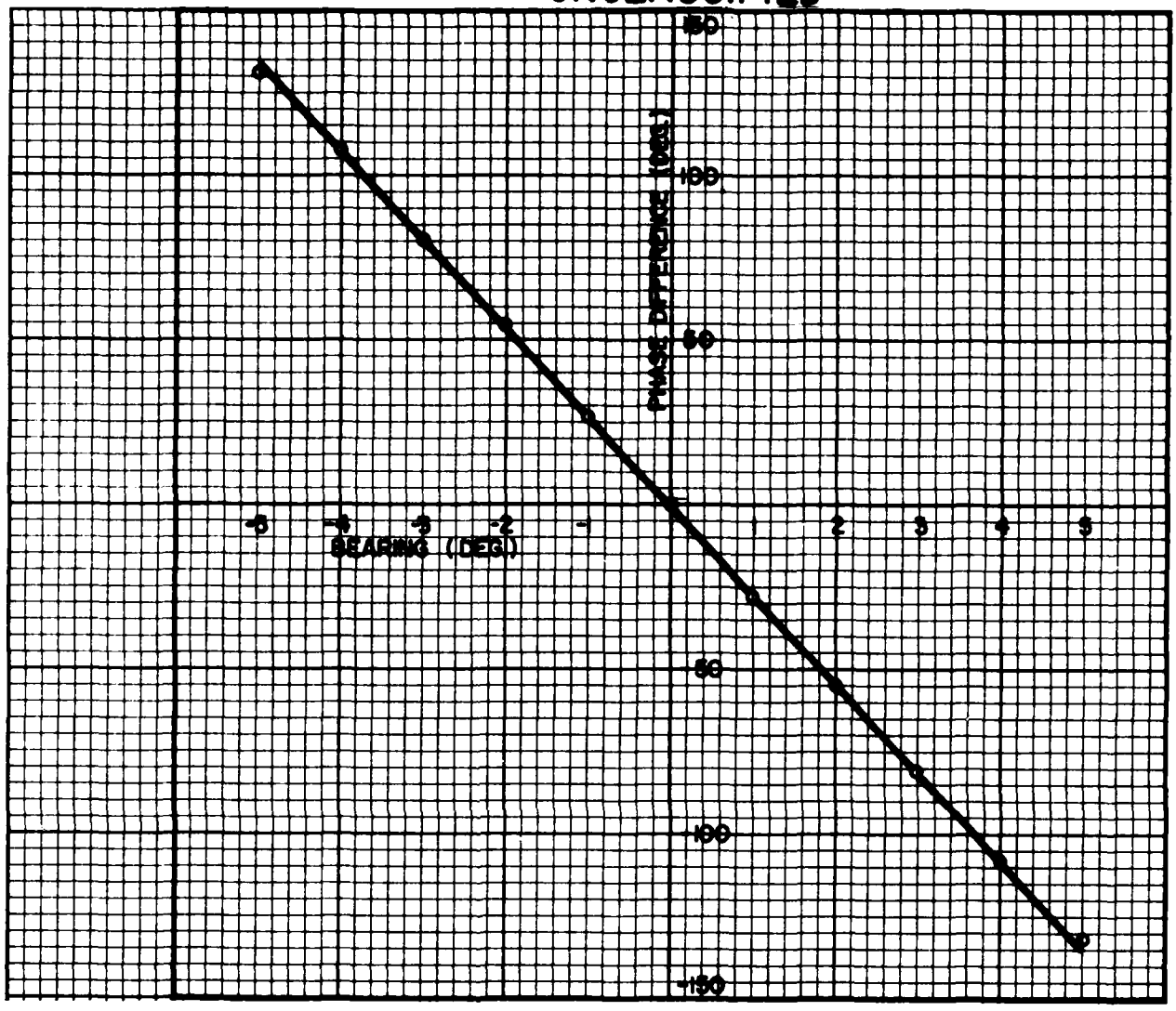

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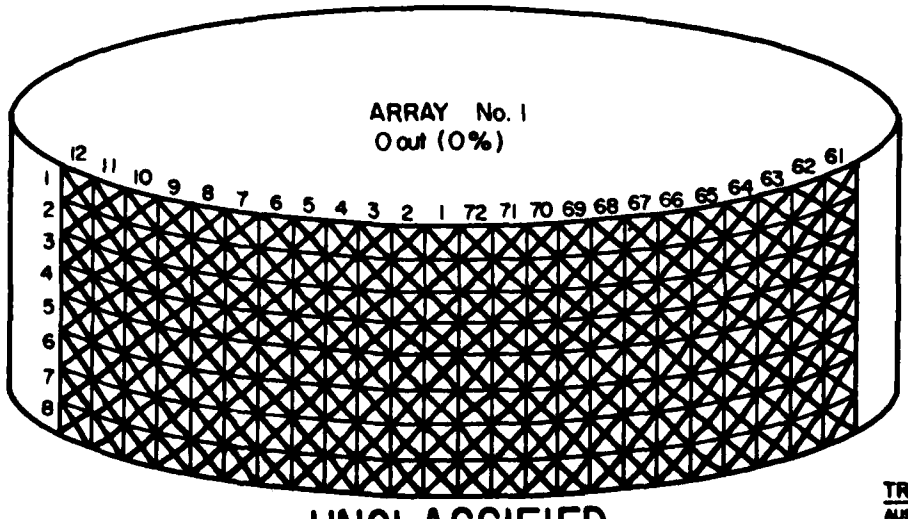

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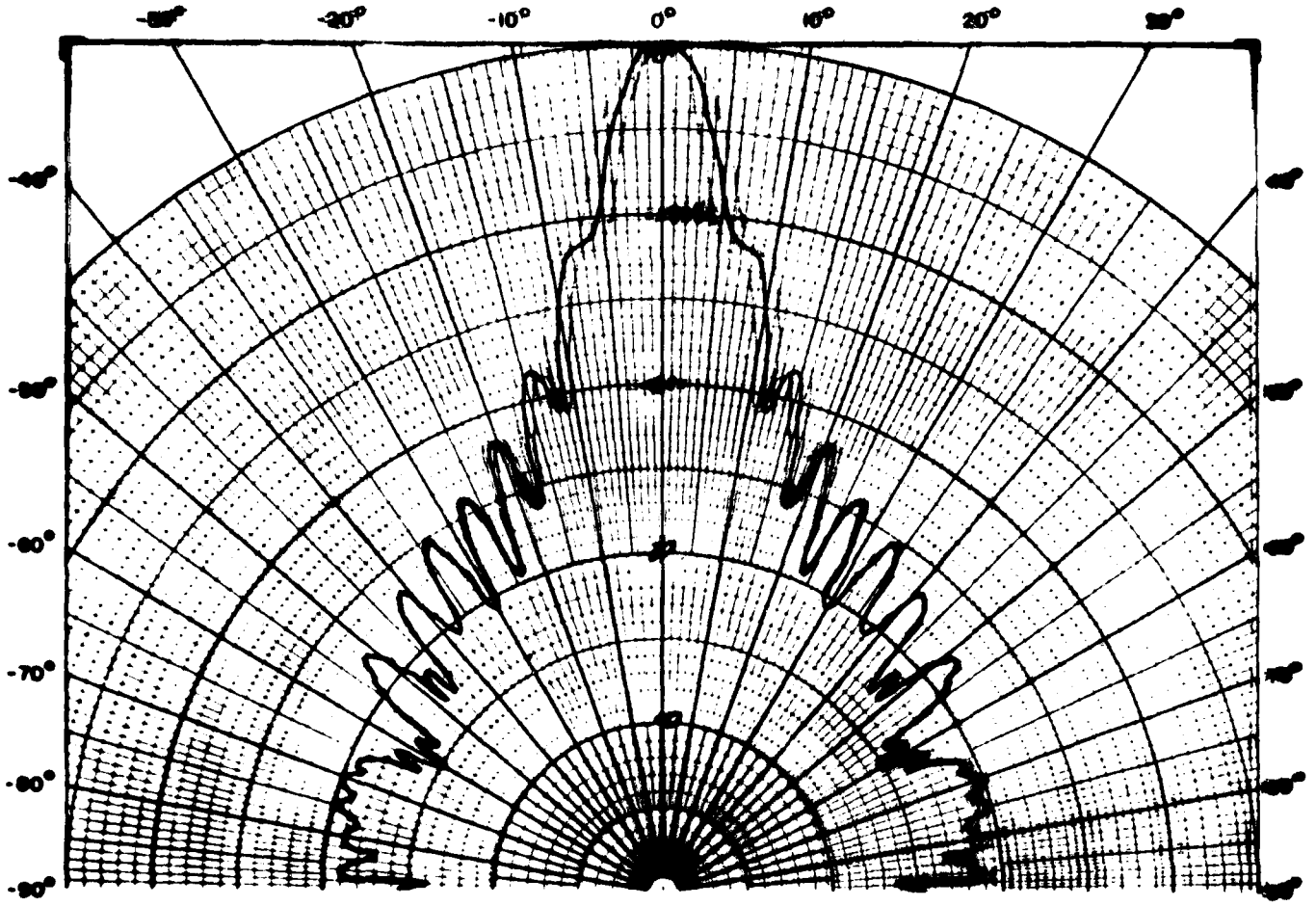

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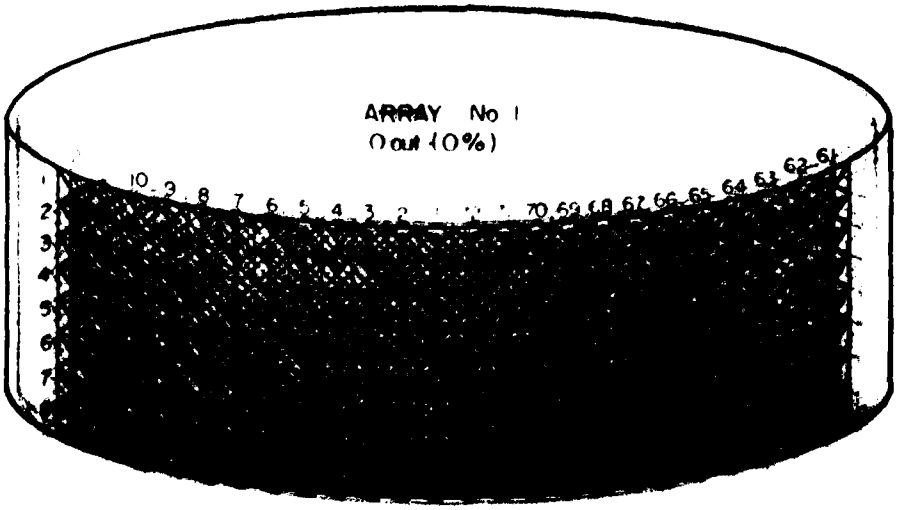

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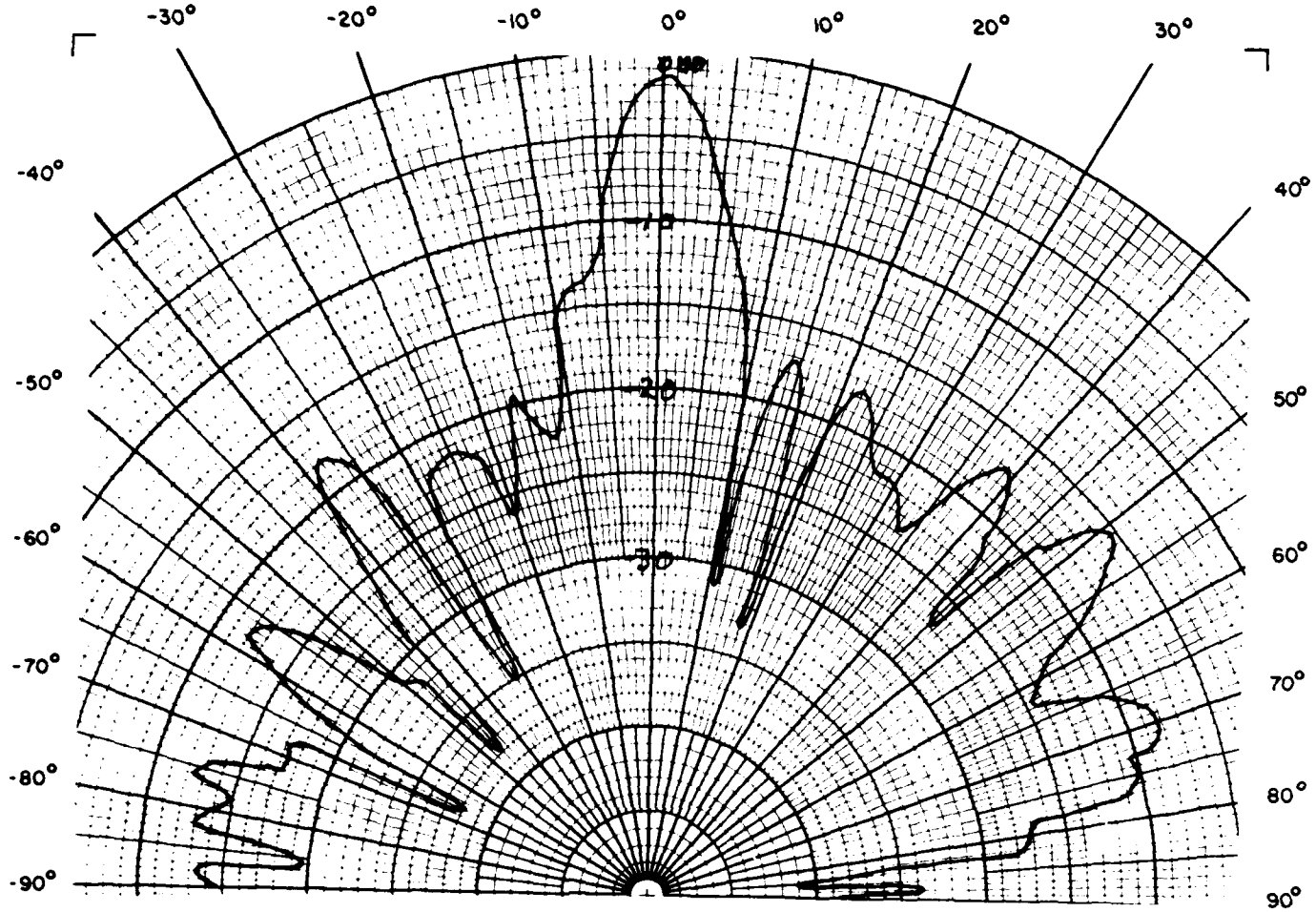

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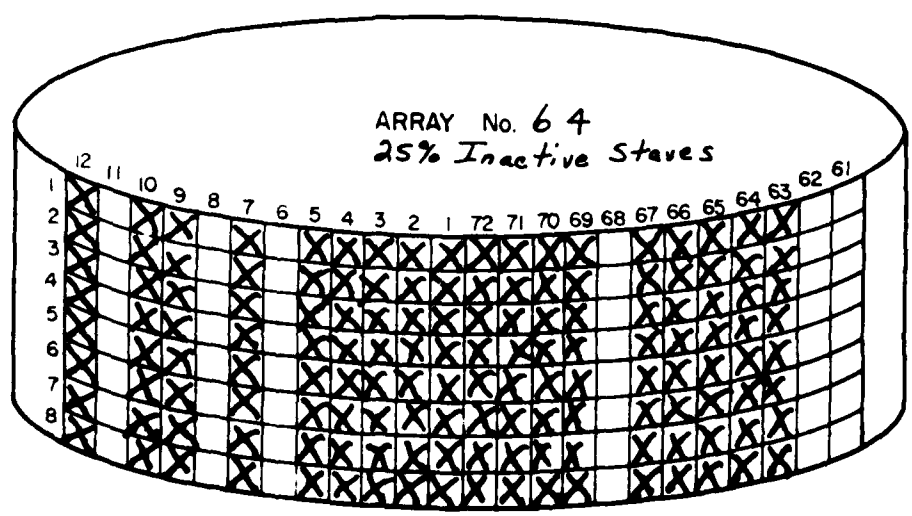

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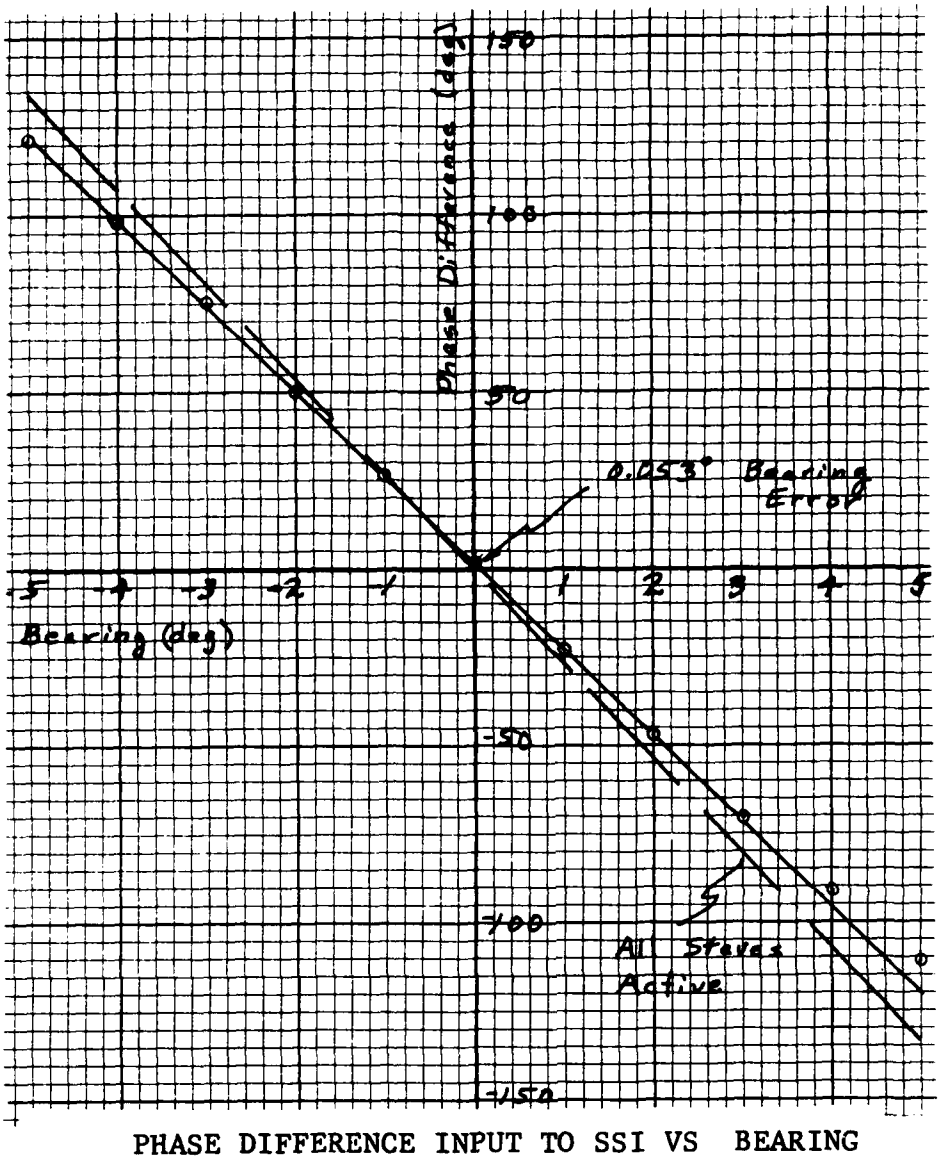

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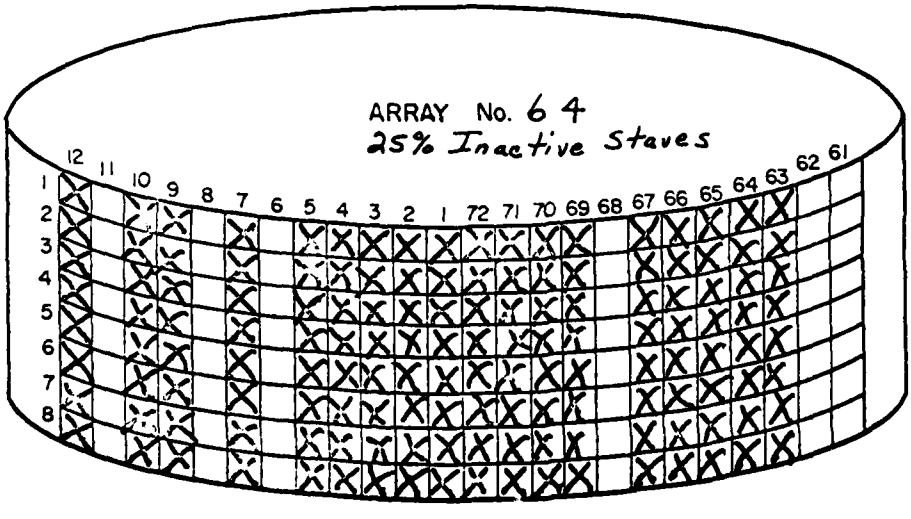

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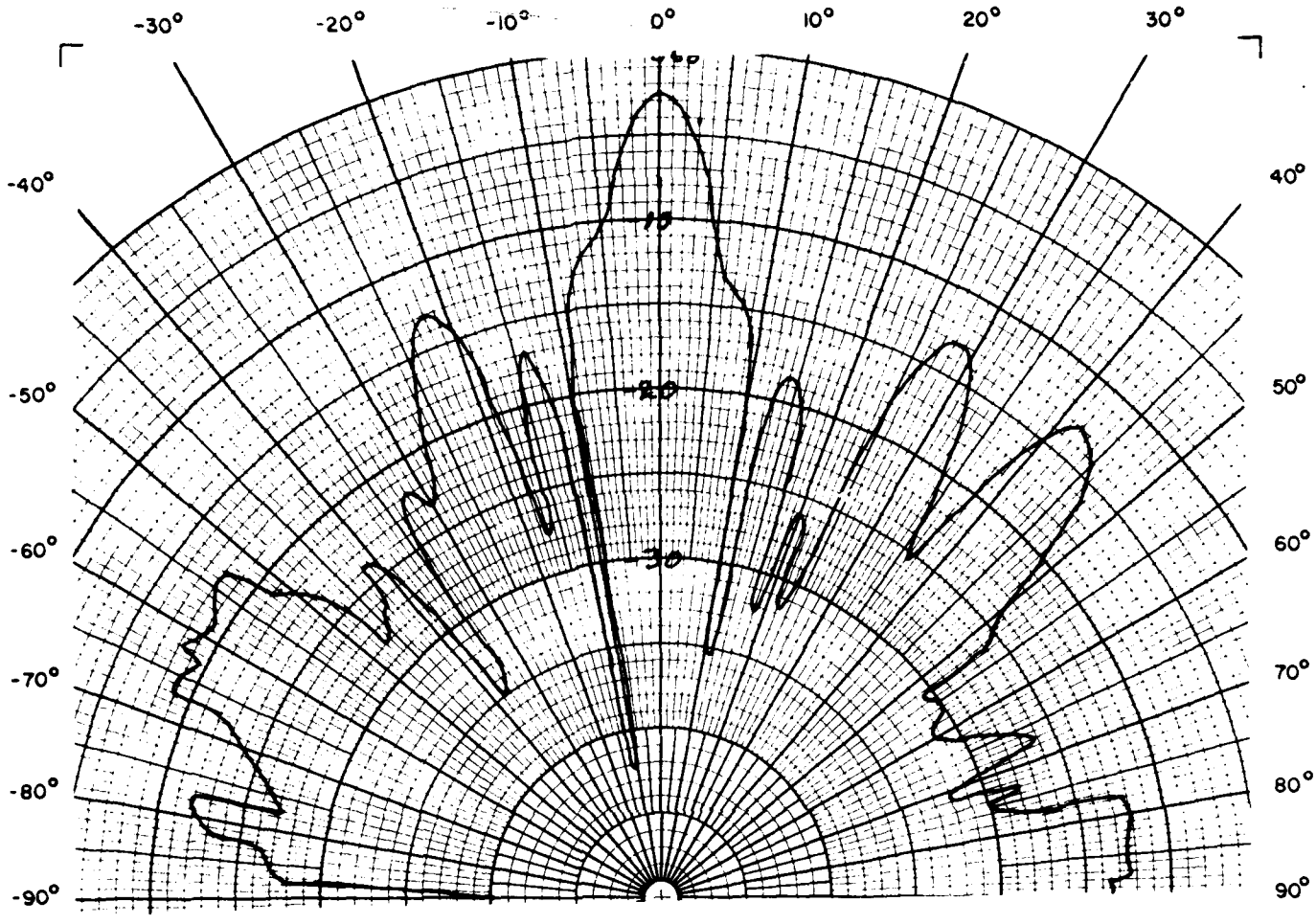

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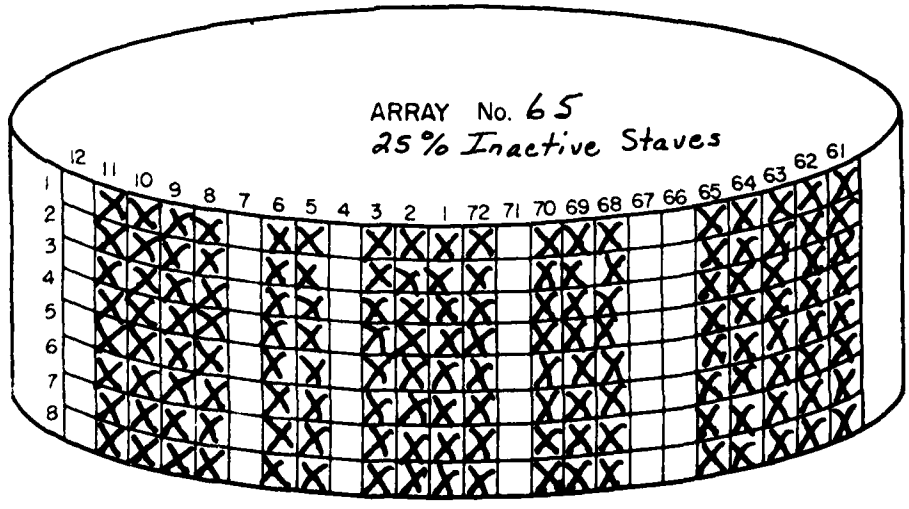

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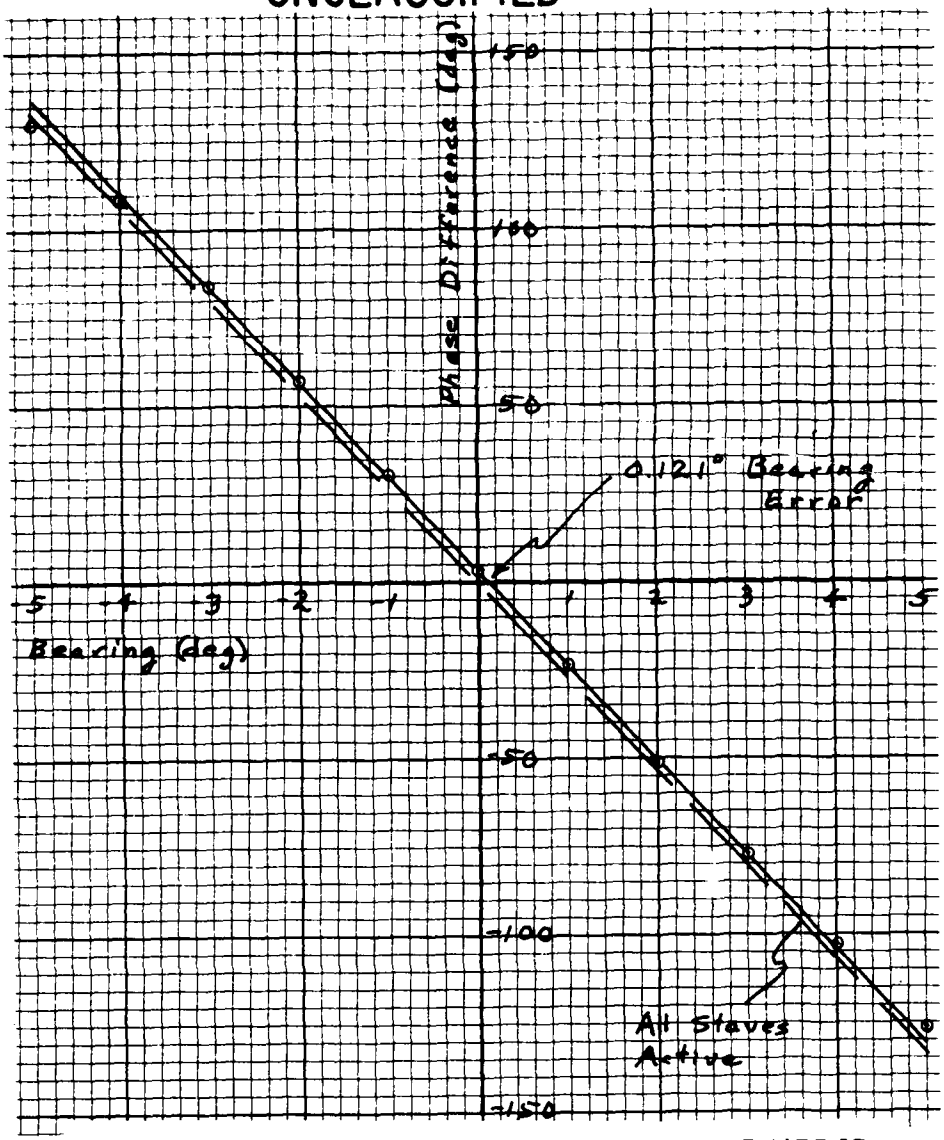
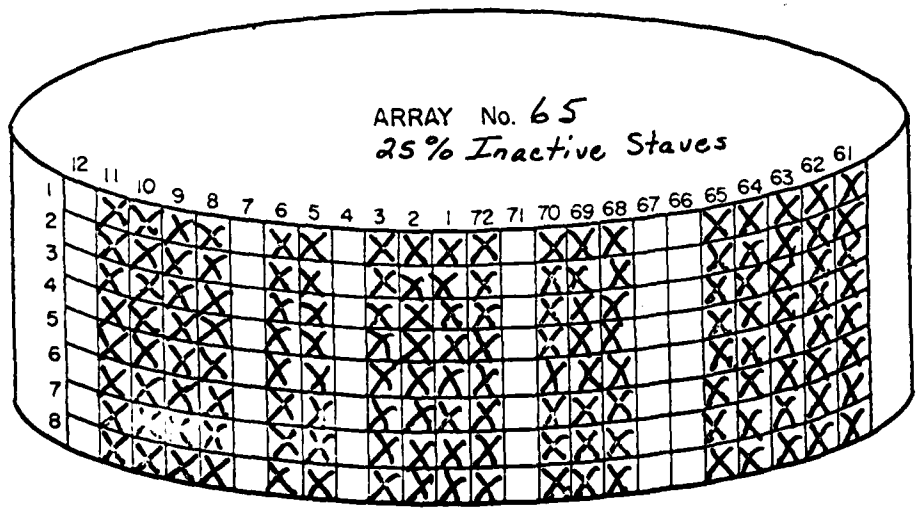


PHASE DIFFERENCE INPUT TO SSI VS BEARING



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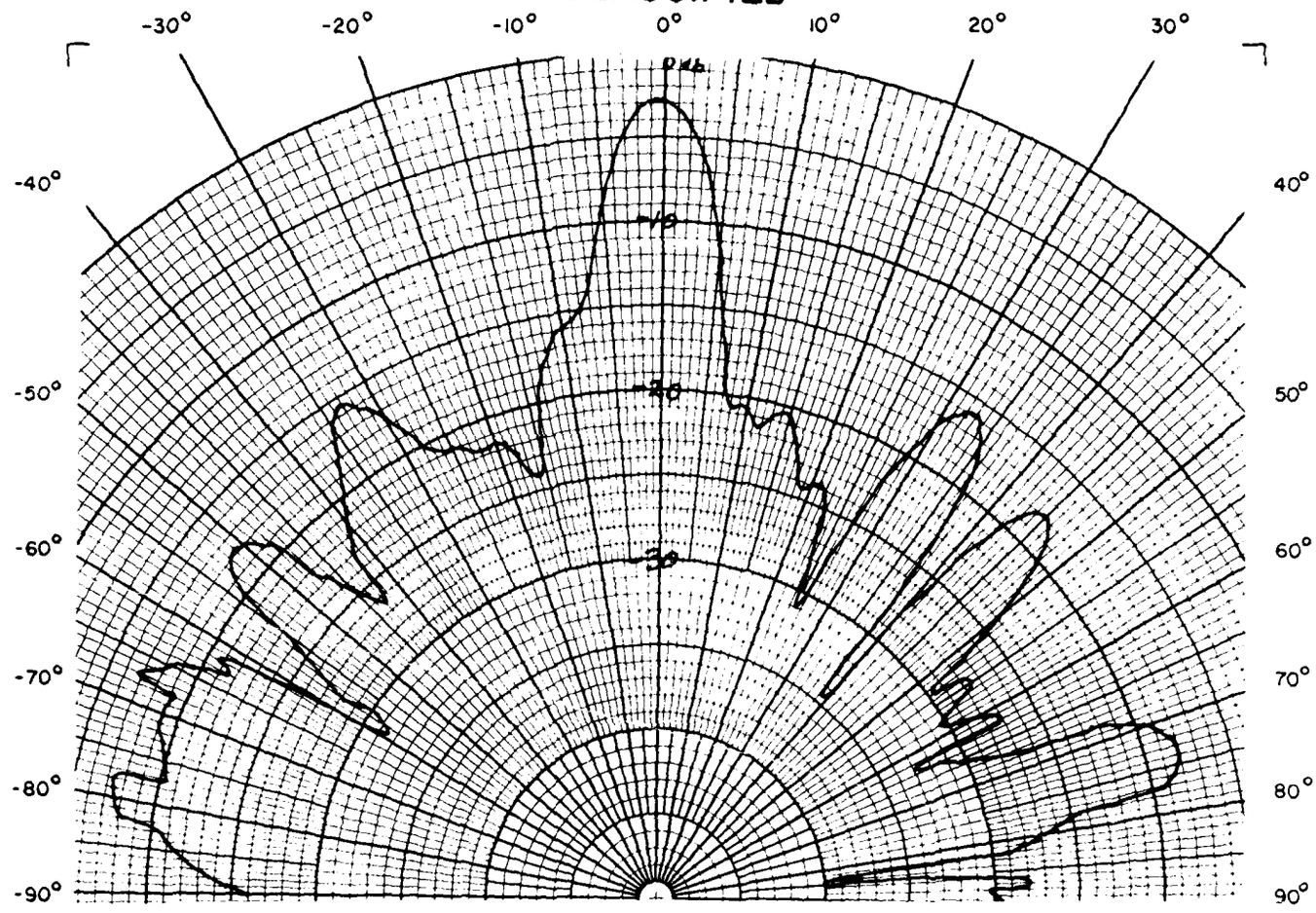
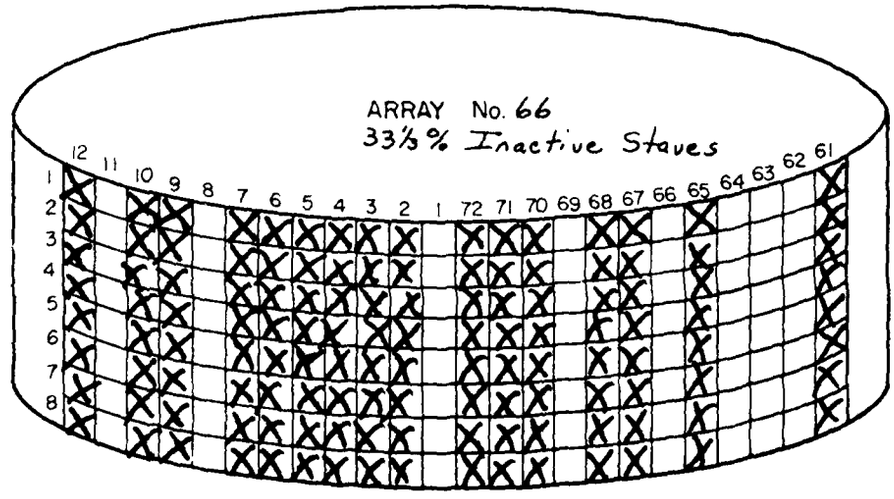
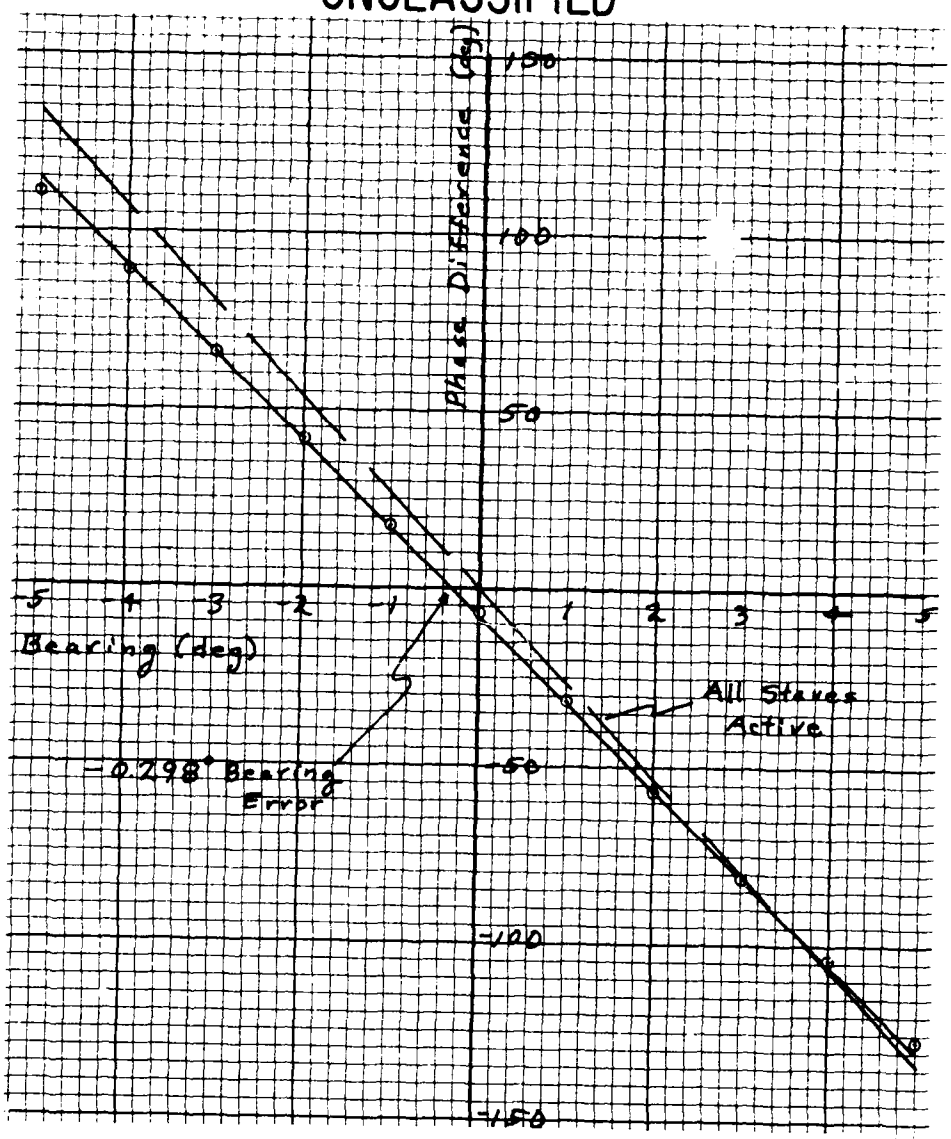


HORIZONTAL RECEIVE BEAM PATTERN
0° TILT ANGLE

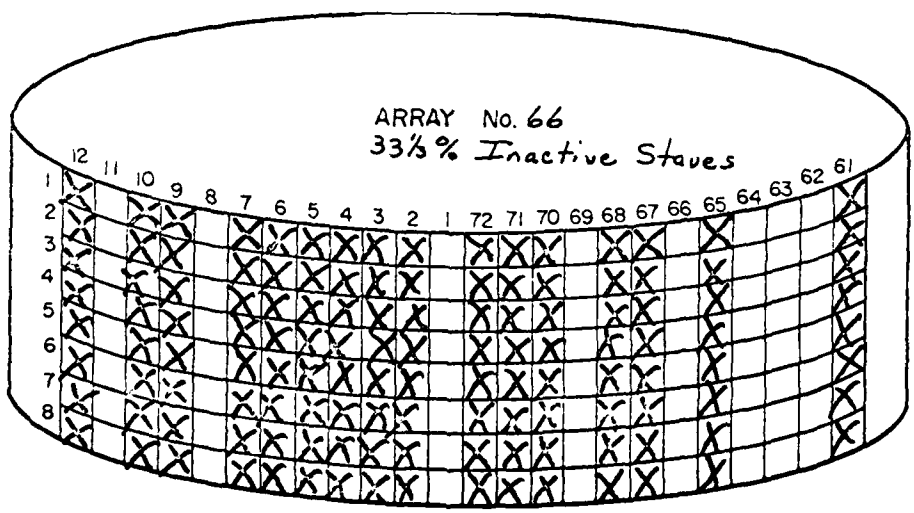


TRACOR, INC
AUSTIN, TEXAS

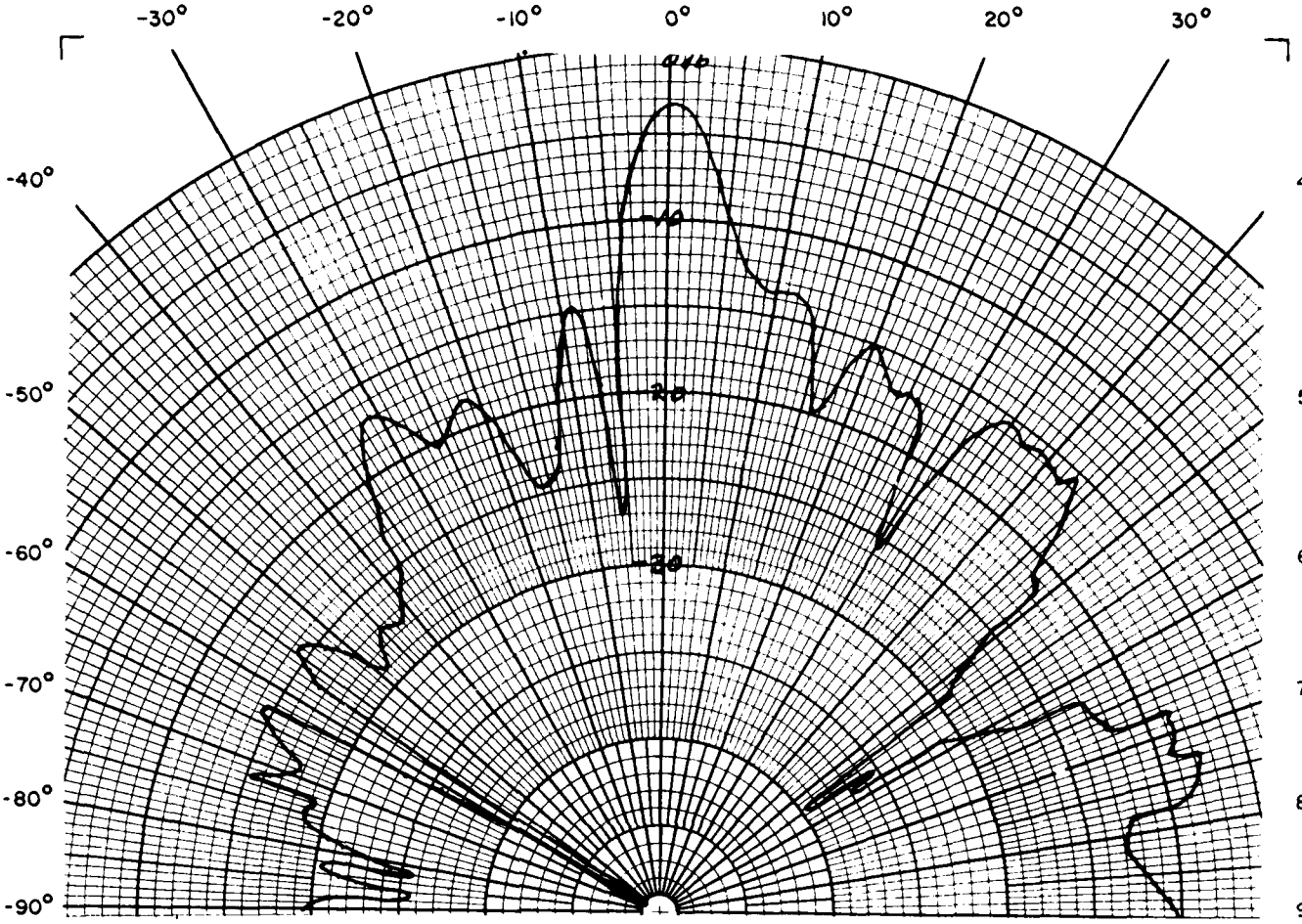
DWG A2000-
GTK-JMY-RPD



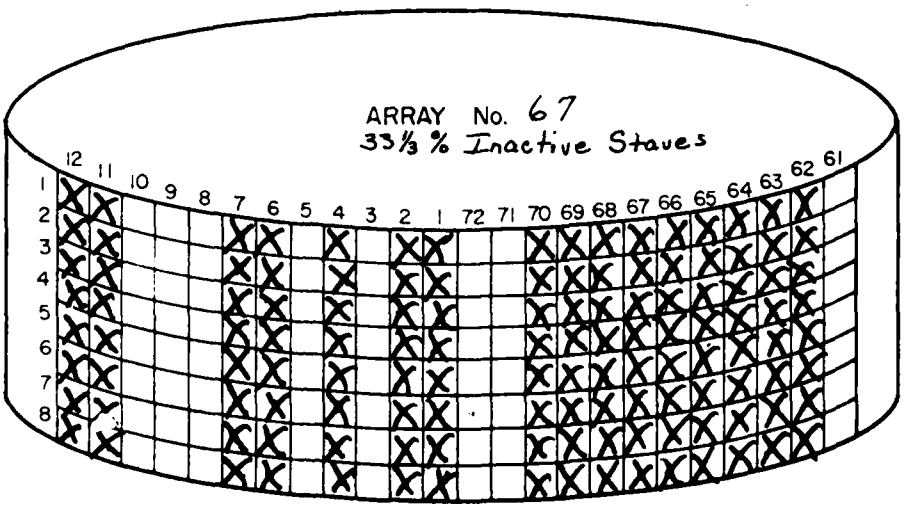
PHASE DIFFERENCE INPUT TO SSI VS BEARING



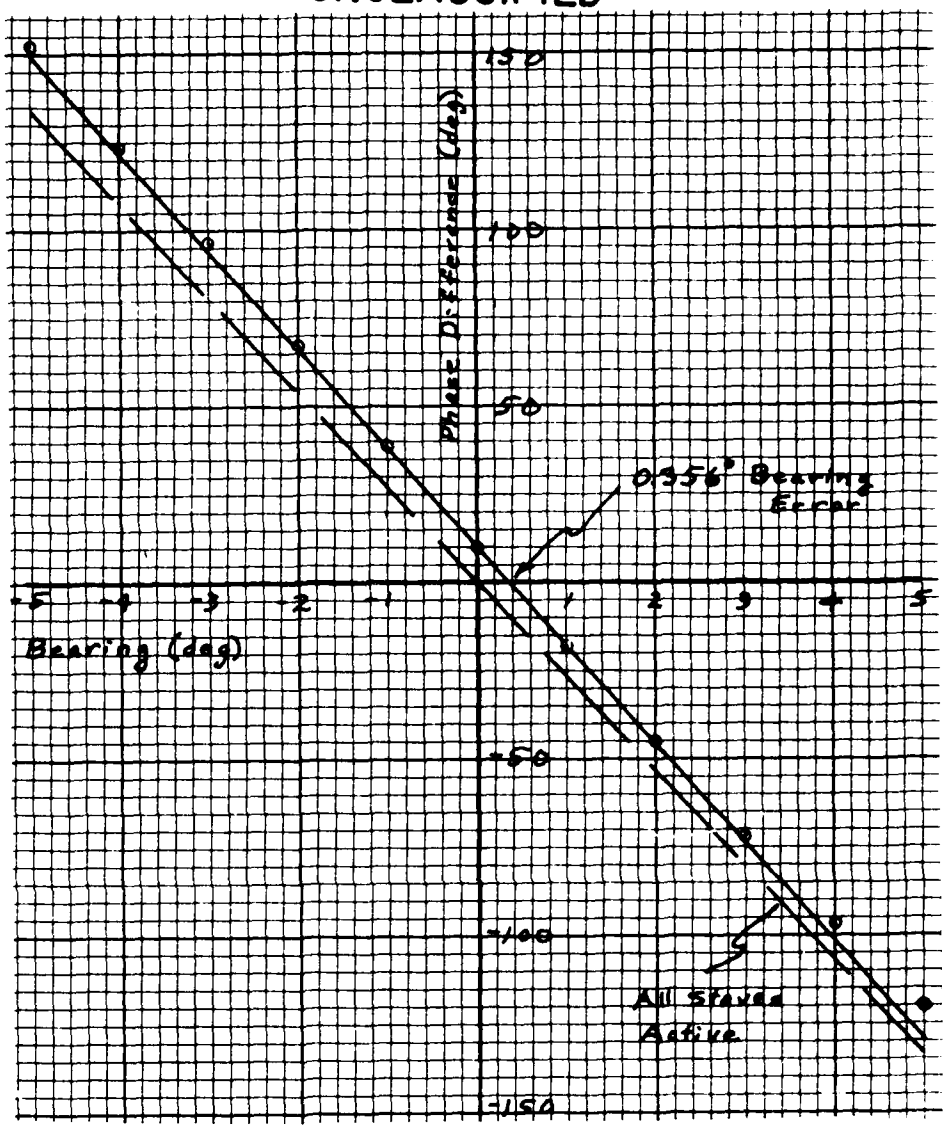
TRACOR, INC. AUSTIN, TEXAS DWG A2000-GTK-JMY-RPD



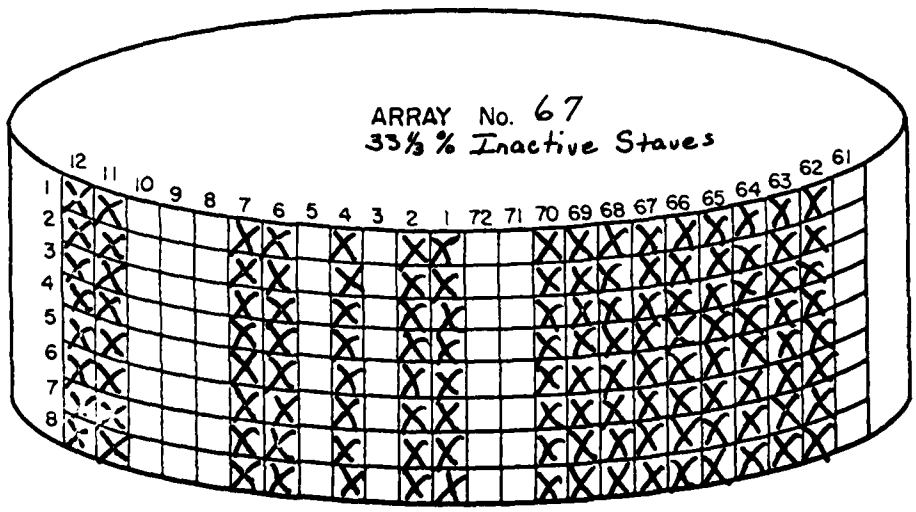
HORIZONTAL RECEIVE BEAM PATTERN
0° TILT ANGLE



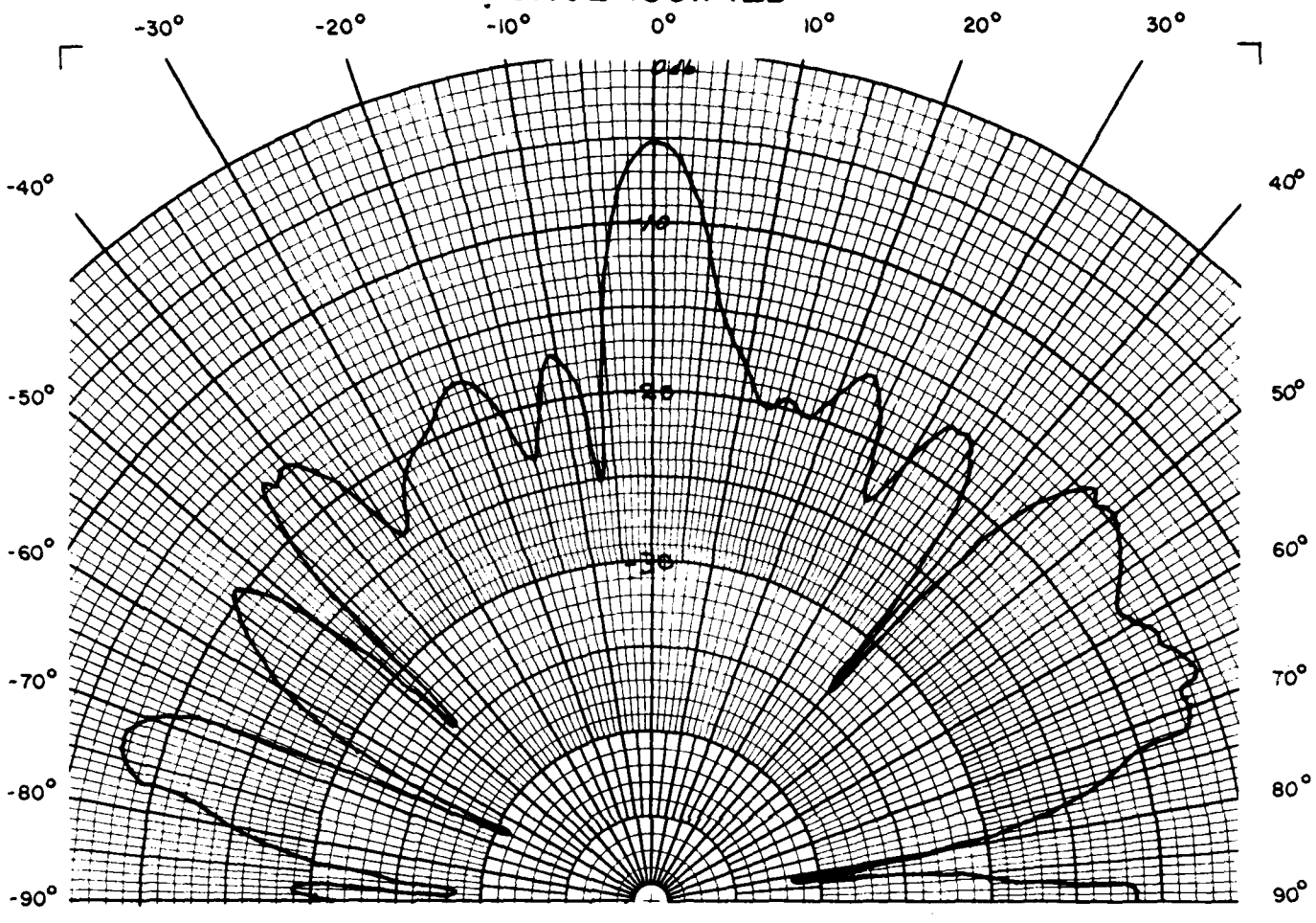
TRACOR, INC AUSTIN, TEXAS — DWG A2000-
GTK-JMY-RPD



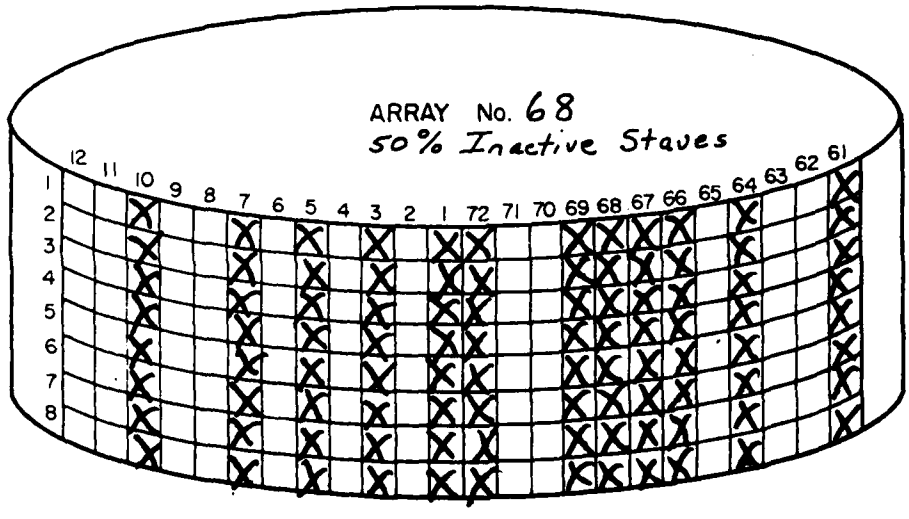
PHASE DIFFERENCE INPUT TO SSI VS BEARING



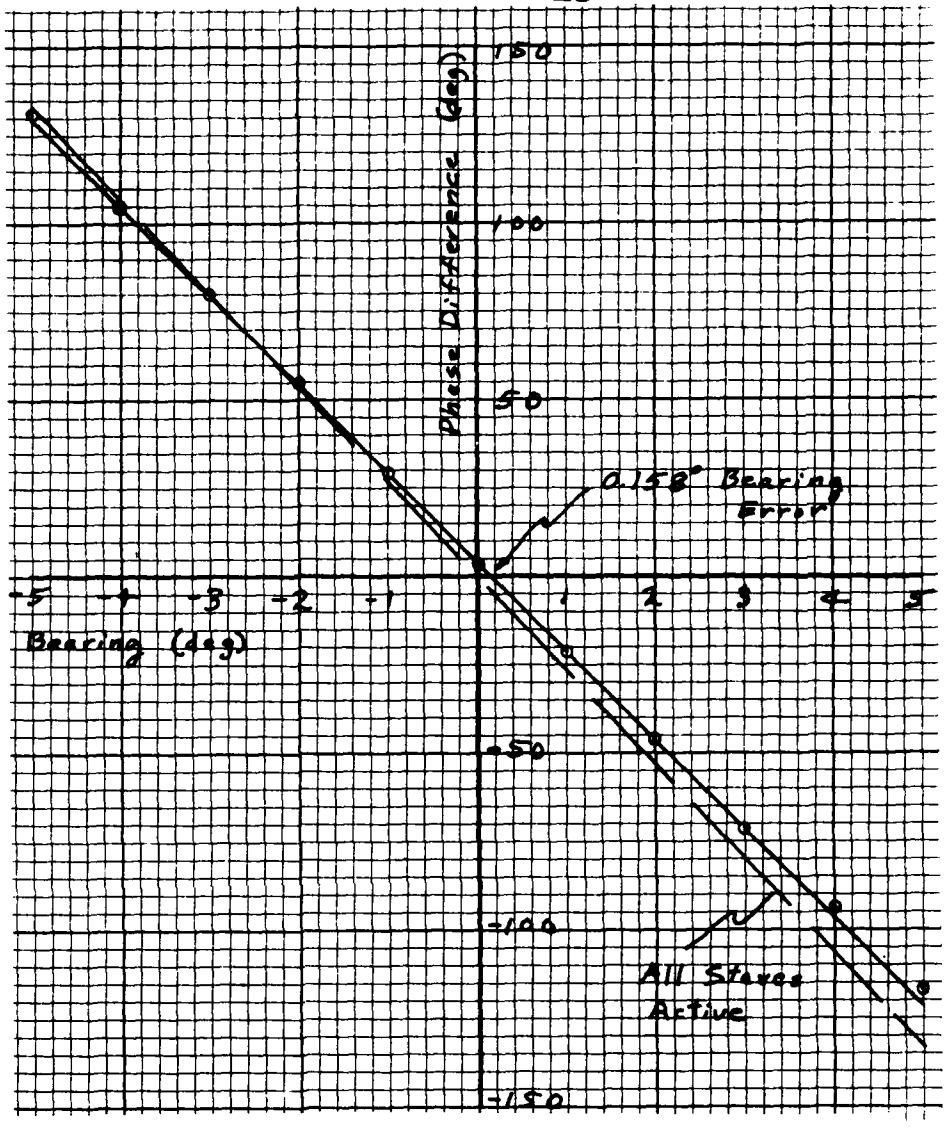
TRACOR, INC. AUSTIN, TEXAS DWG A2000-GTK-JMY-RPD



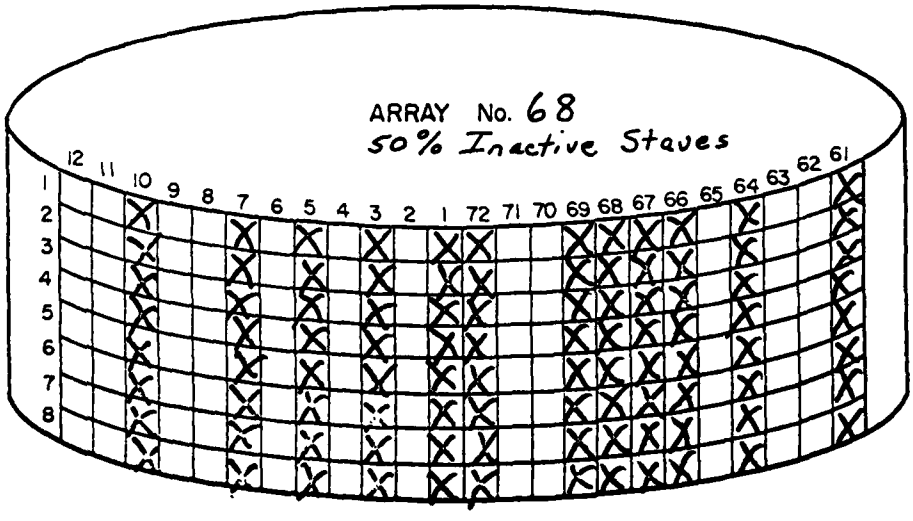
HORIZONTAL RECEIVE BEAM PATTERN
0° TILT ANGLE



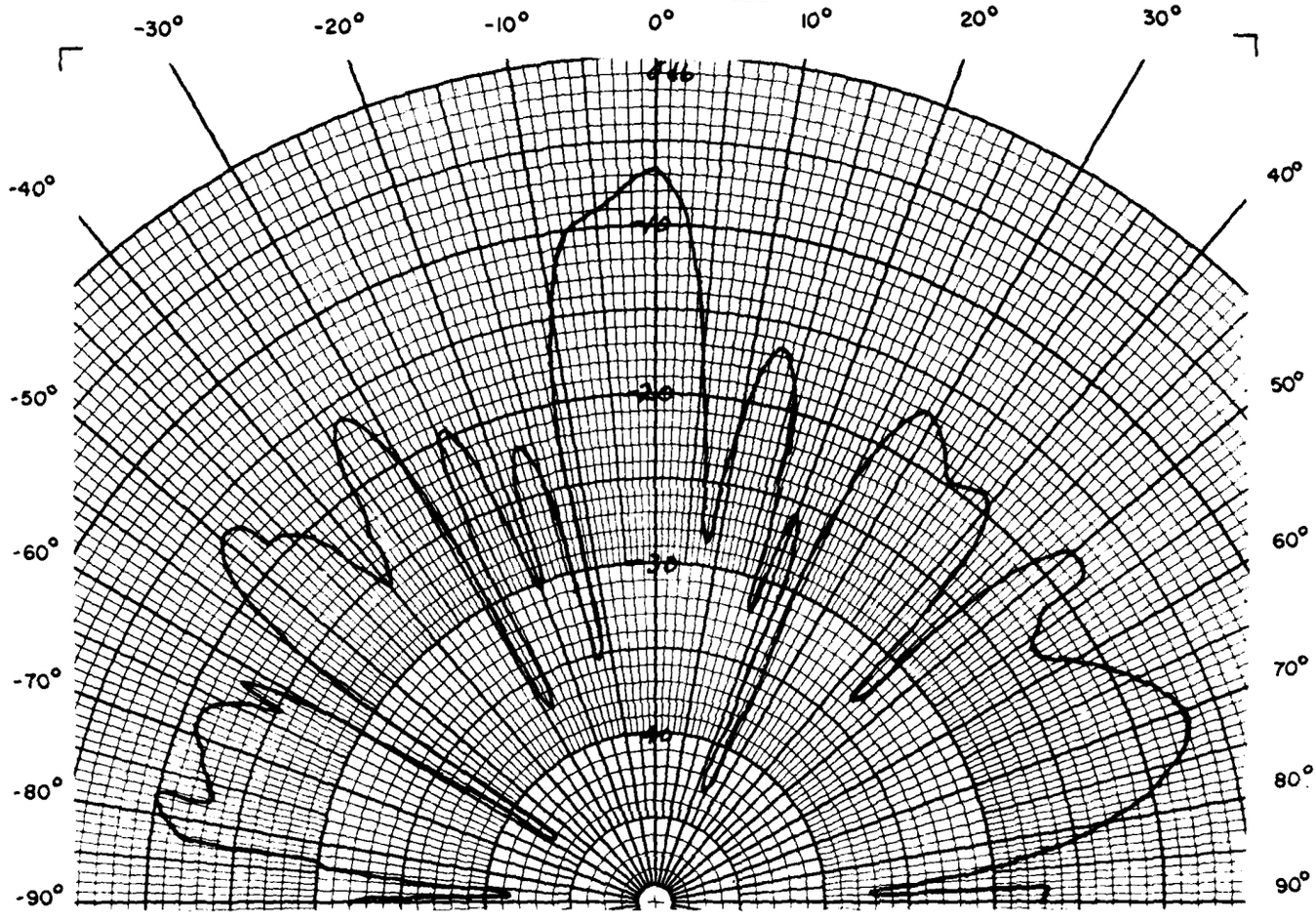
TRACOR, INC. AUSTIN, TEXAS DWG. A2000-GTK-JMY-RPD



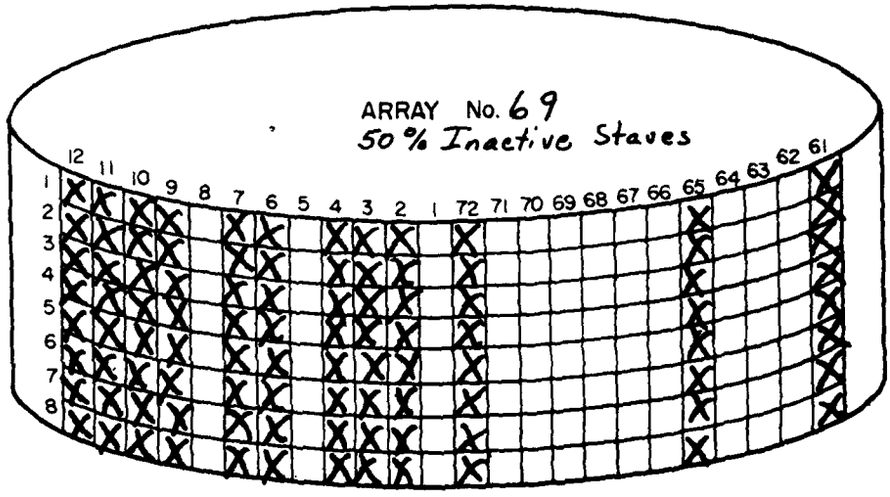
PHASE DIFFERENCE INPUT TO SSI VS BEARING



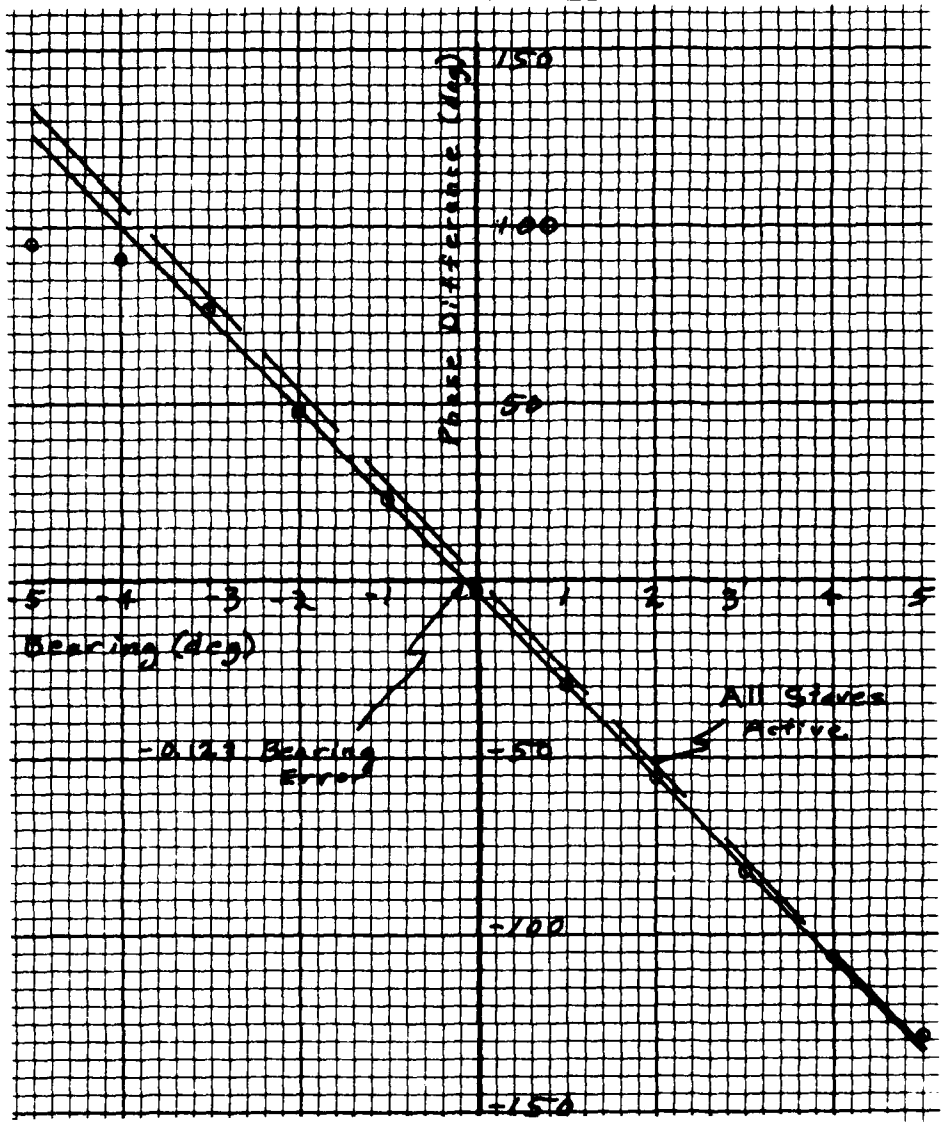
TRACOR, INC. AUSTIN, TEXAS DWG. A2000-
GTK-JMY-RPD



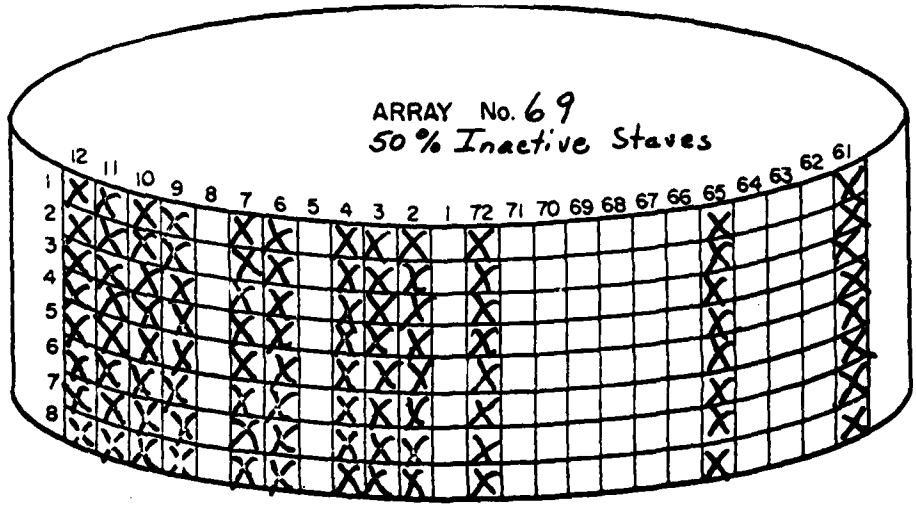
HORIZONTAL RECEIVE BEAM PATTERN
0° TILT ANGLE



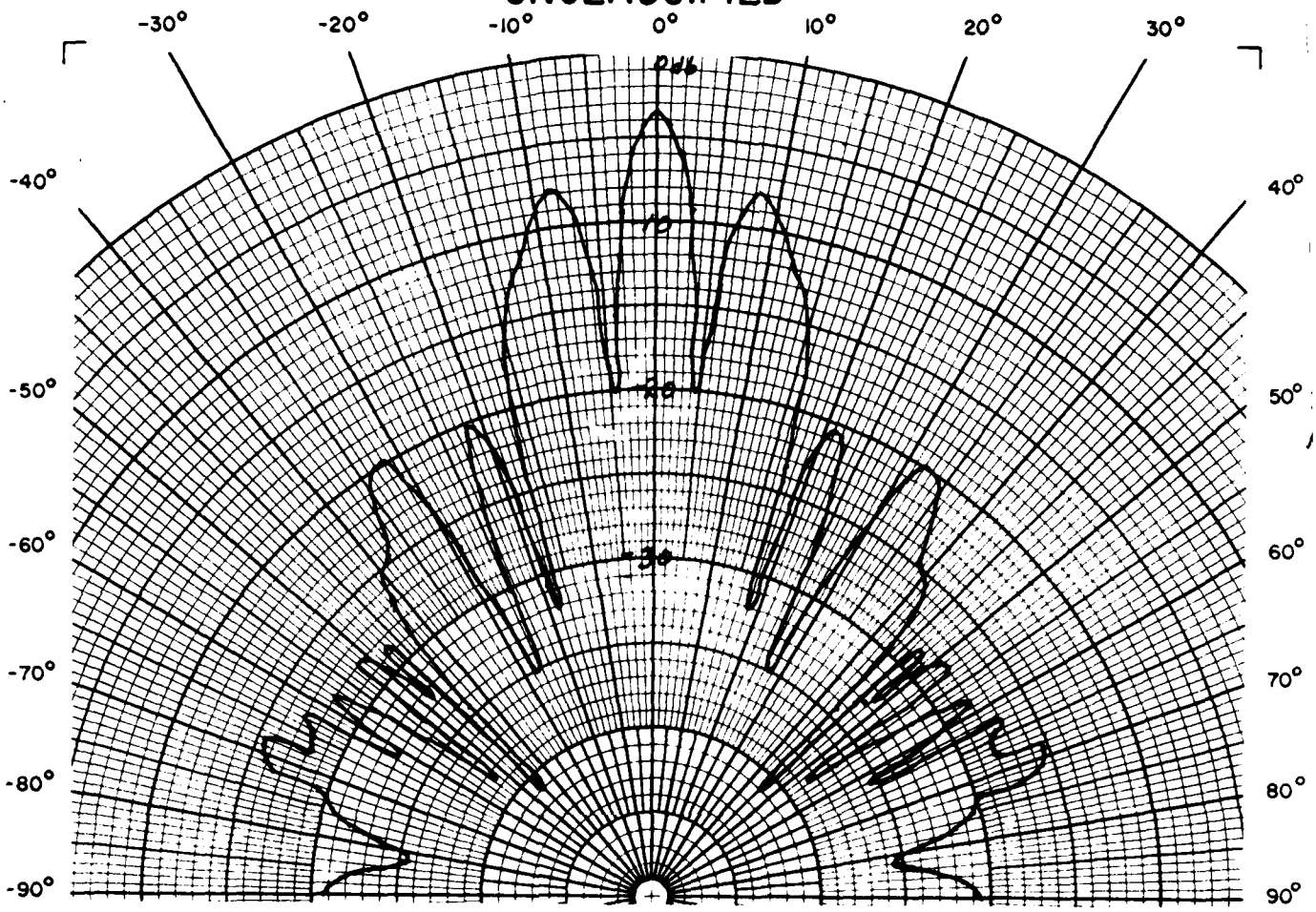
TRACOR, INC. AUSTIN, TEXAS DWG A2000-
GTK-JMY-RPD



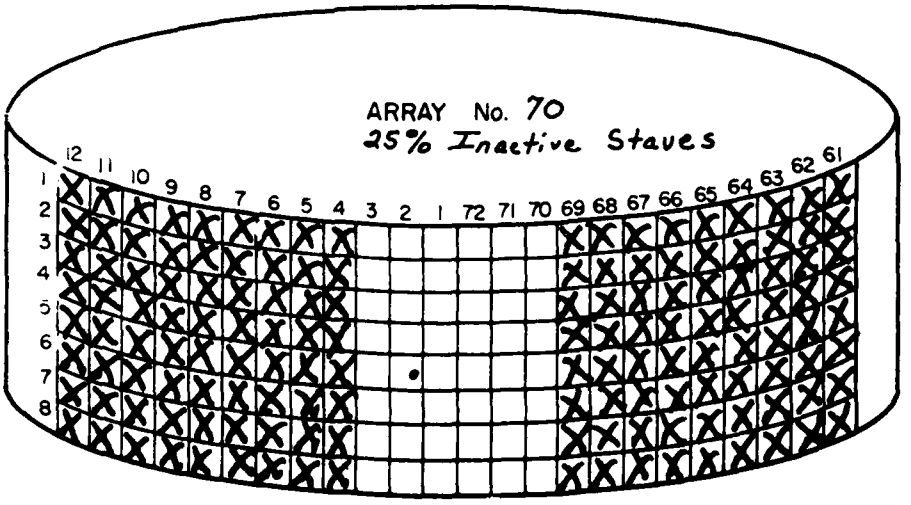
PHASE DIFFERENCE INPUT TO SSI VS. BEARING



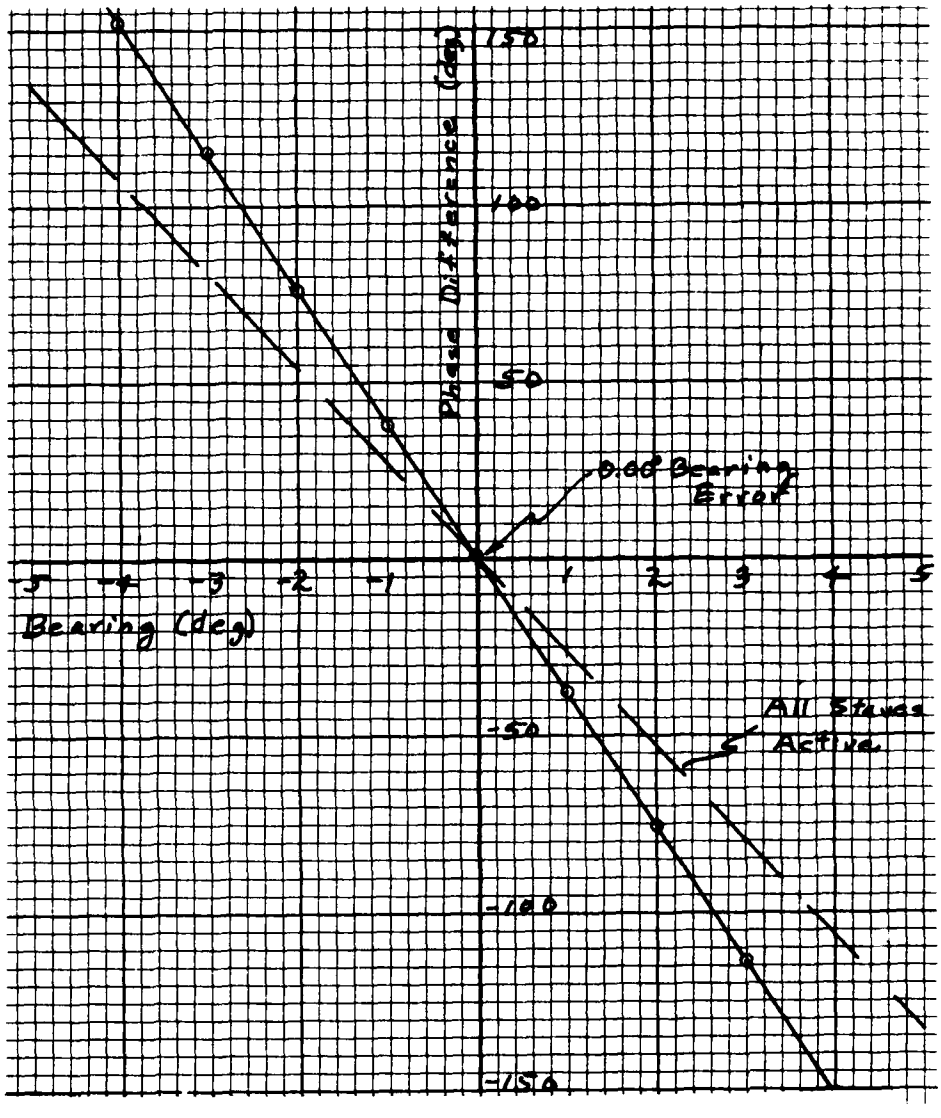
TRACOR, INC. AUSTIN, TEXAS DWG A2000-
STK-JMY-RPD



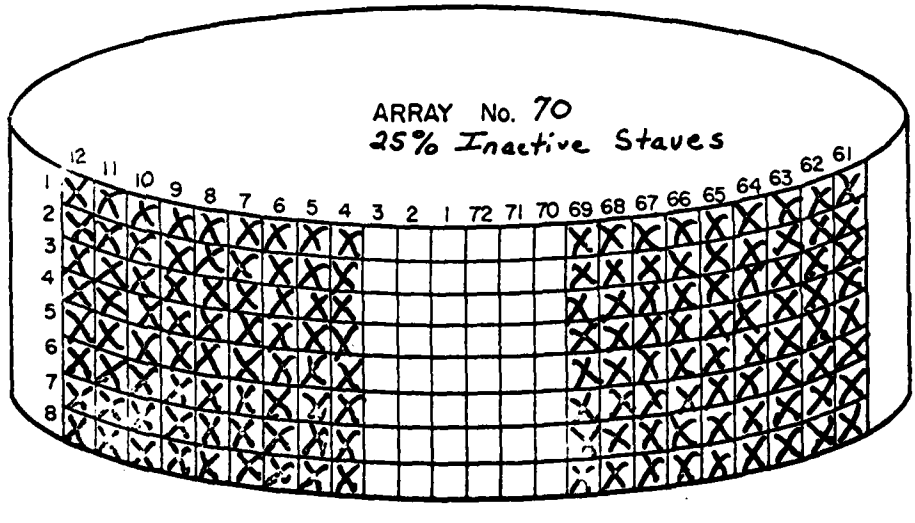
HORIZONTAL RECEIVE BEAM PATTERN
0° TILT ANGLE



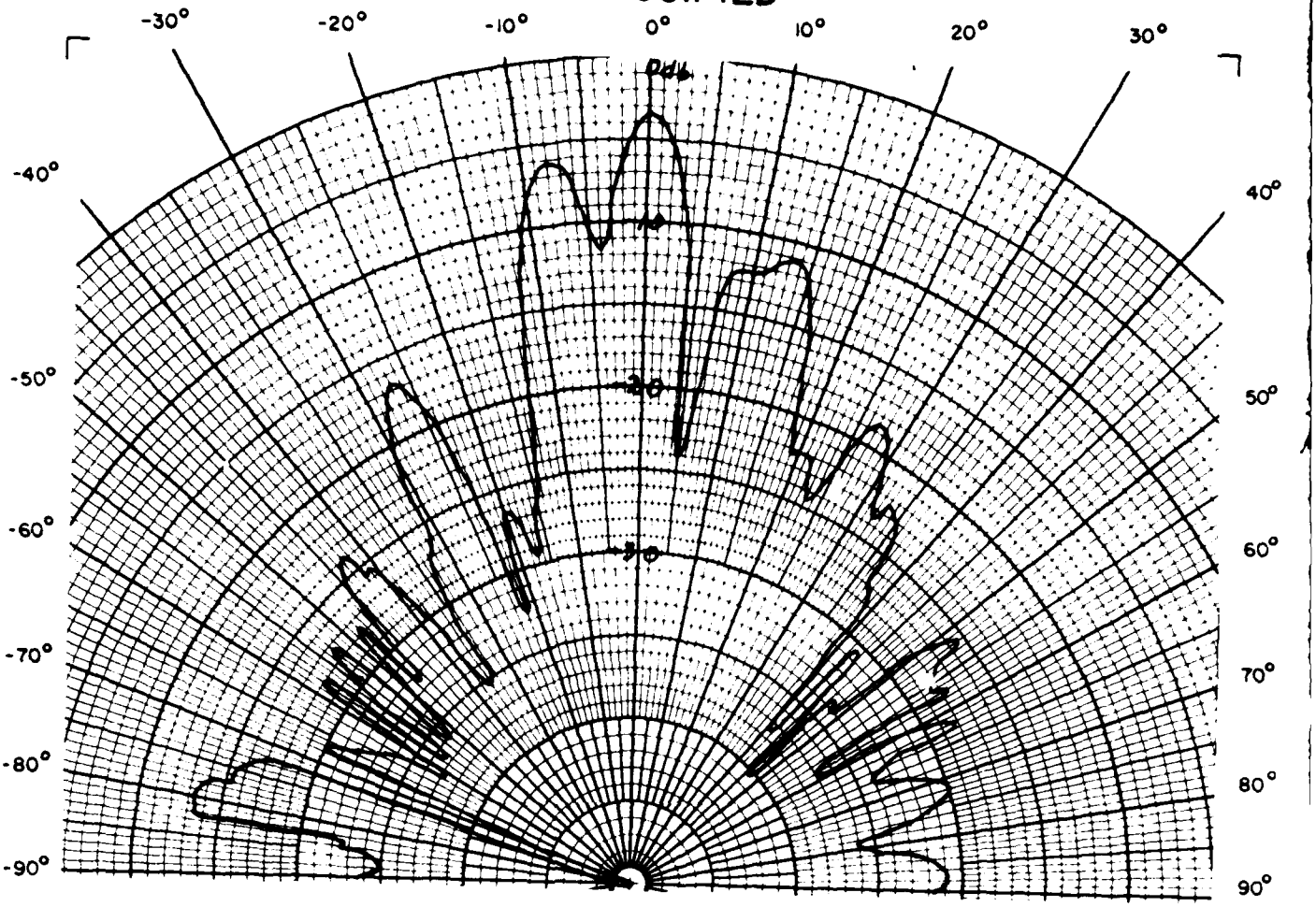
TRACOR, INC. AUSTIN, TEXAS DWG A2000-
GTK-JMY-RPD



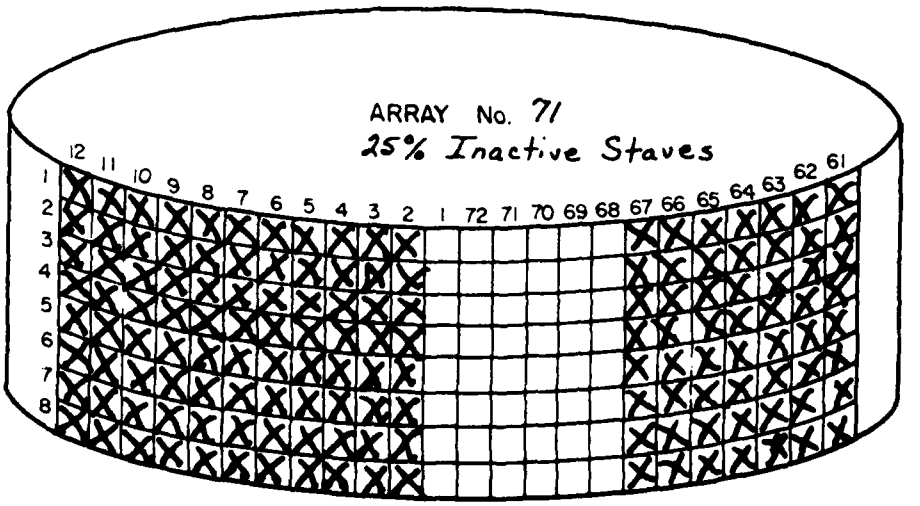
PHASE DIFFERENCE INPUT TO SSI VS BEARING



TRACOR, INC. DWG. A2000-
AUSTIN, TEXAS 6TK-JMY-RPD

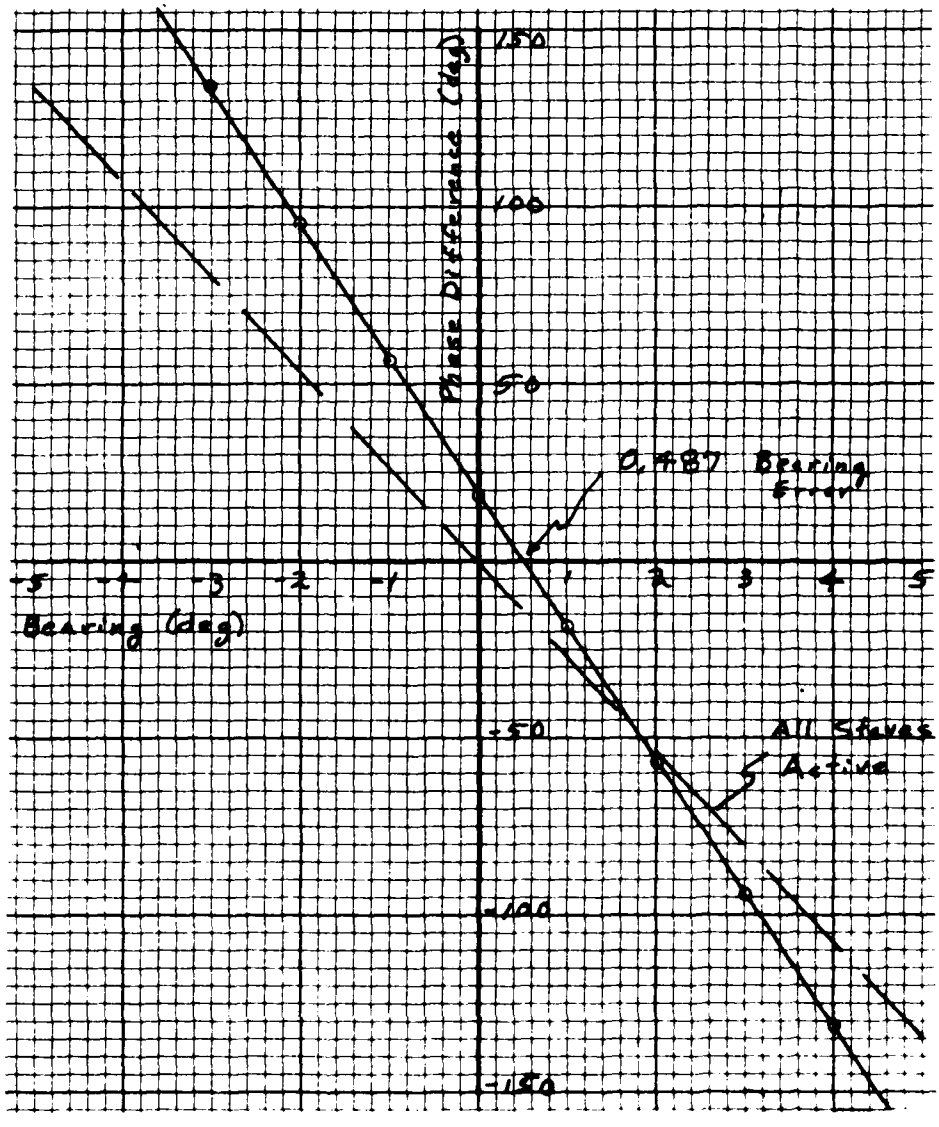


HORIZONTAL RECEIVE BEAM PATTERN
0° TILT ANGLE

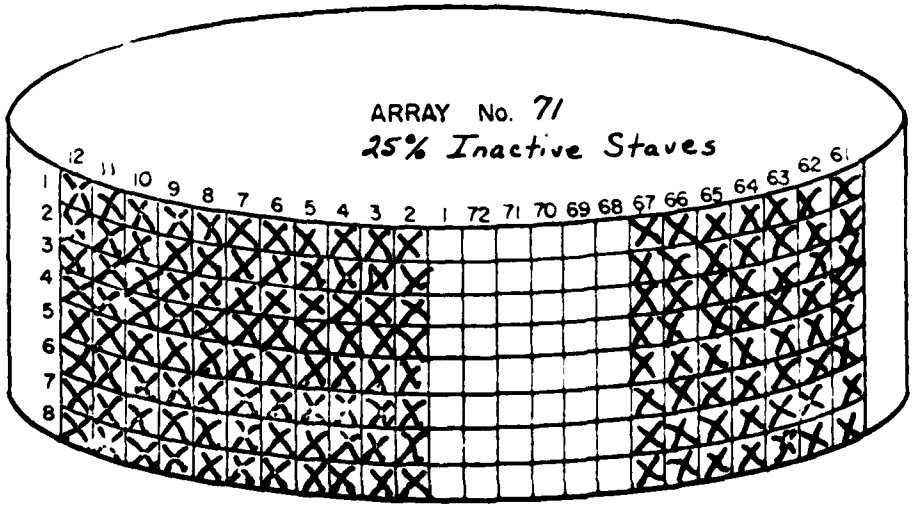


TRACOR, INC
AUSTIN, TEXAS

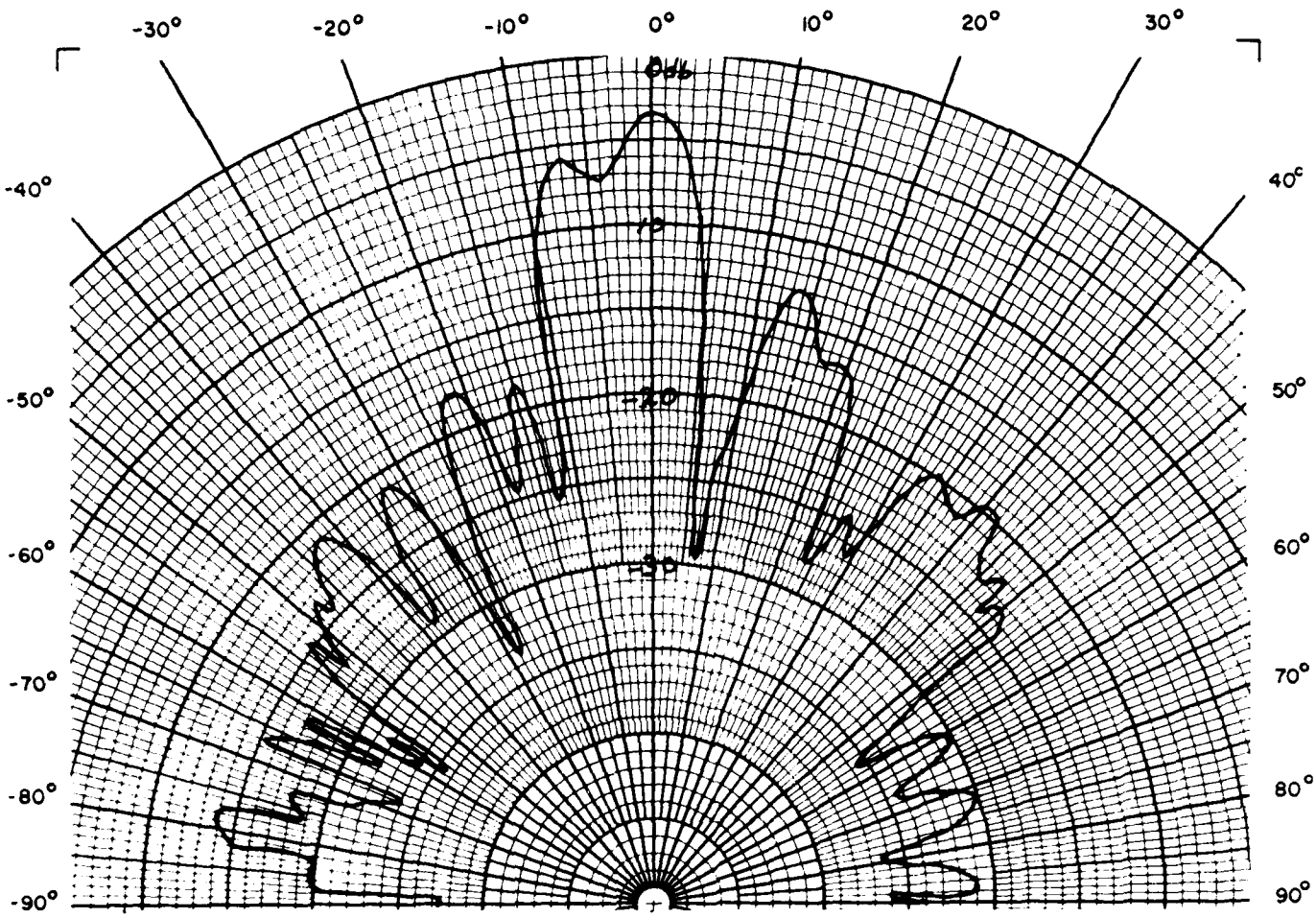
DWG A2000-
GTK-JMY-RPD



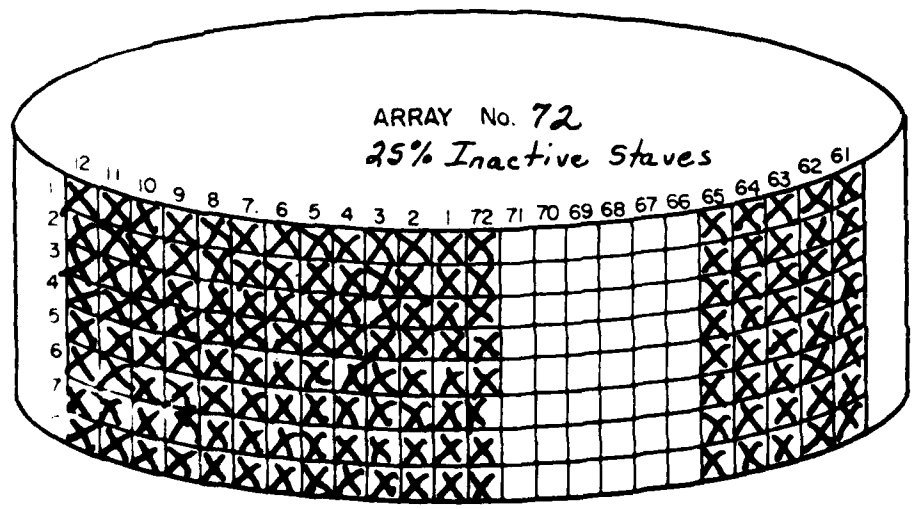
PHASE DIFFERENCE INPUT TO SSI VS BEARING



TRACOR, INC AUSTIN, TEXAS DWG A2000-
GTK-JMY-RPD



HORIZONTAL RECEIVE BEAM PATTERN
0° TILT ANGLE



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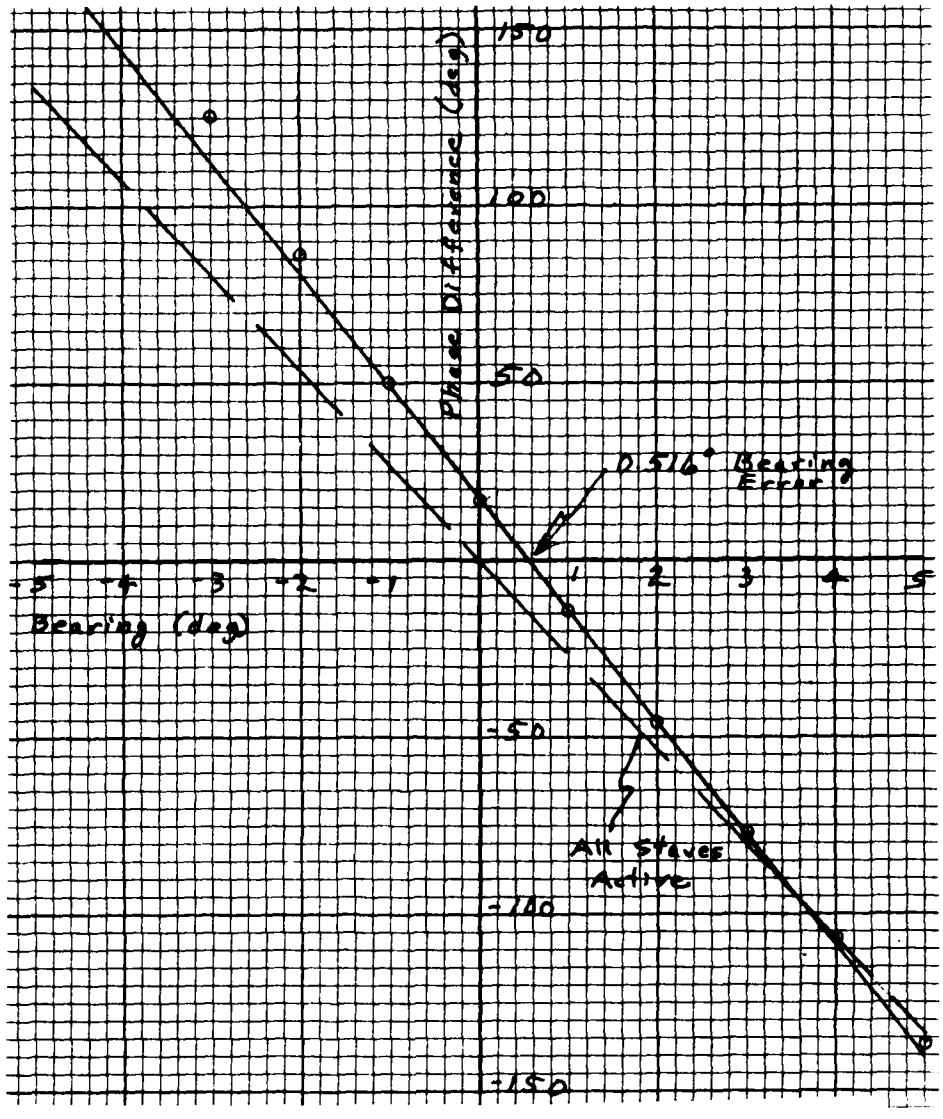
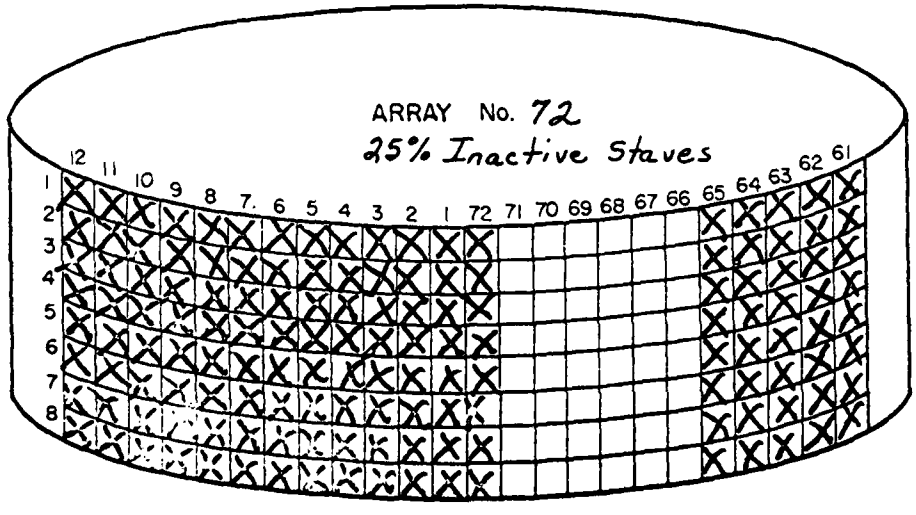
AUSTIN, TEXAS

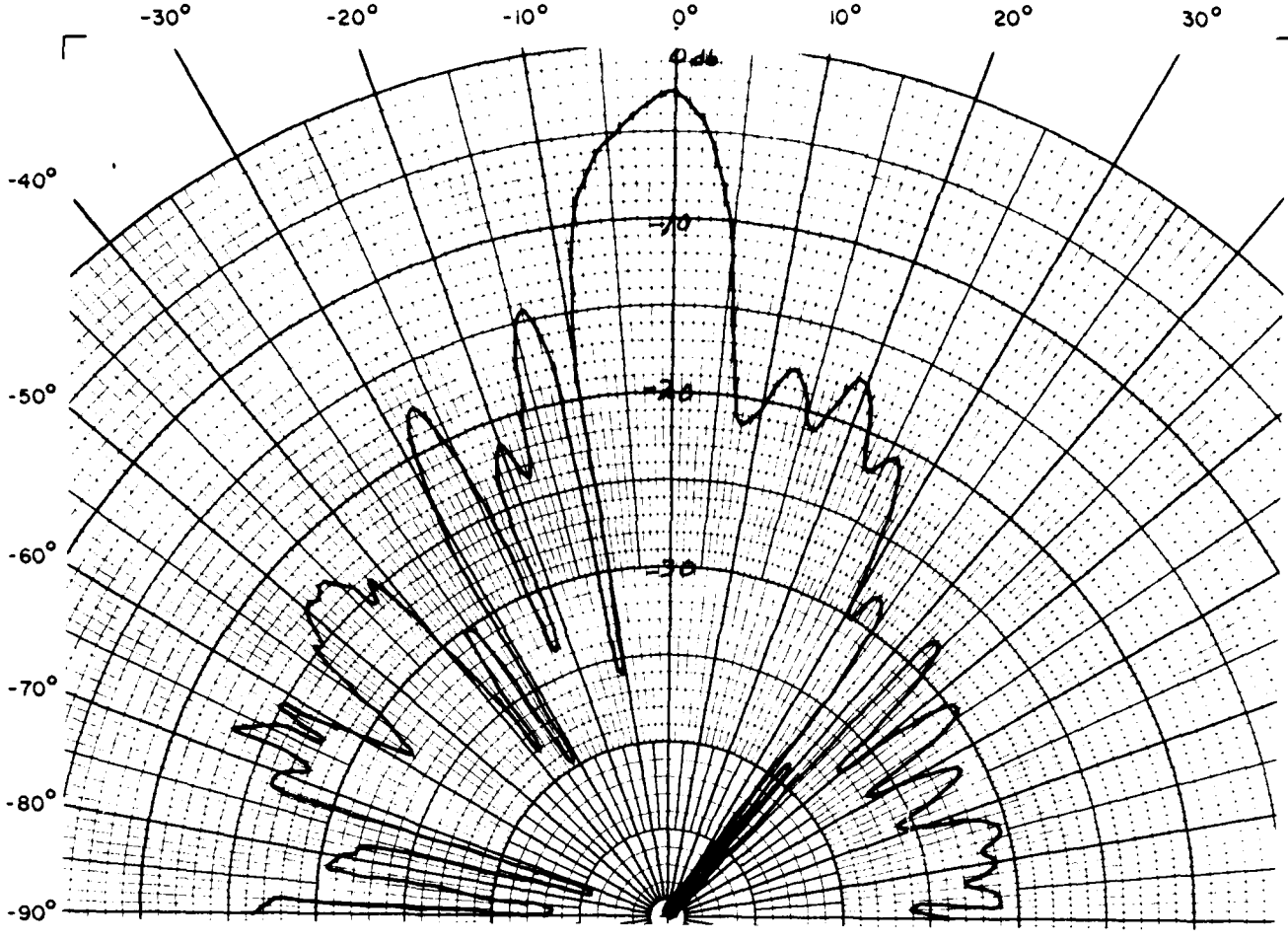
DWG A2000-
GTK-JMY-RPD



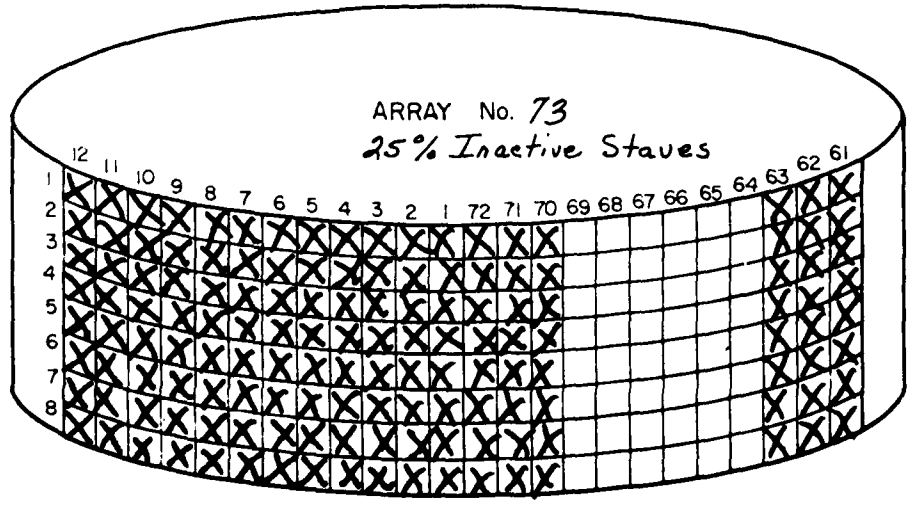
PHASE DIFFERENCE INPUT TO SSI VS BEARING



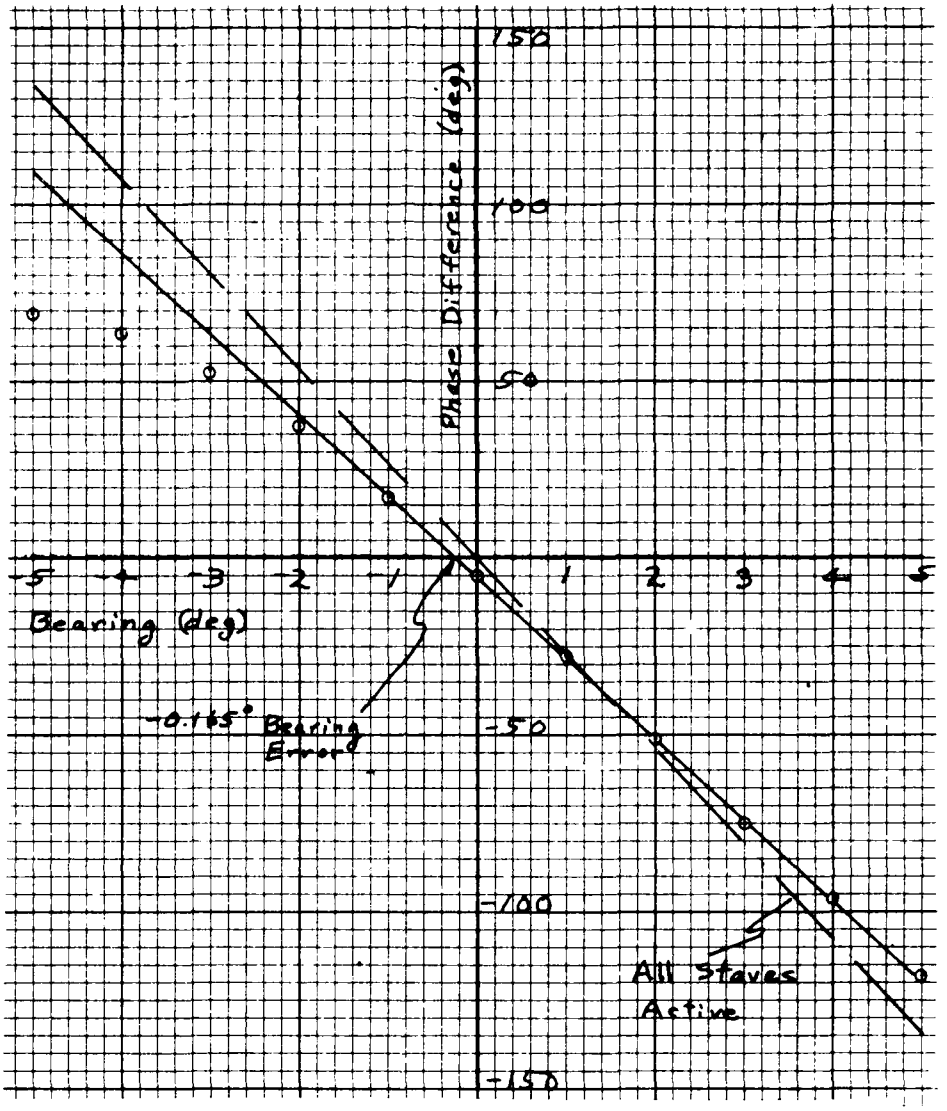
TRACOR, INC. AUSTIN, TEXAS DWG. A2000-
GTK-JMY-RPD



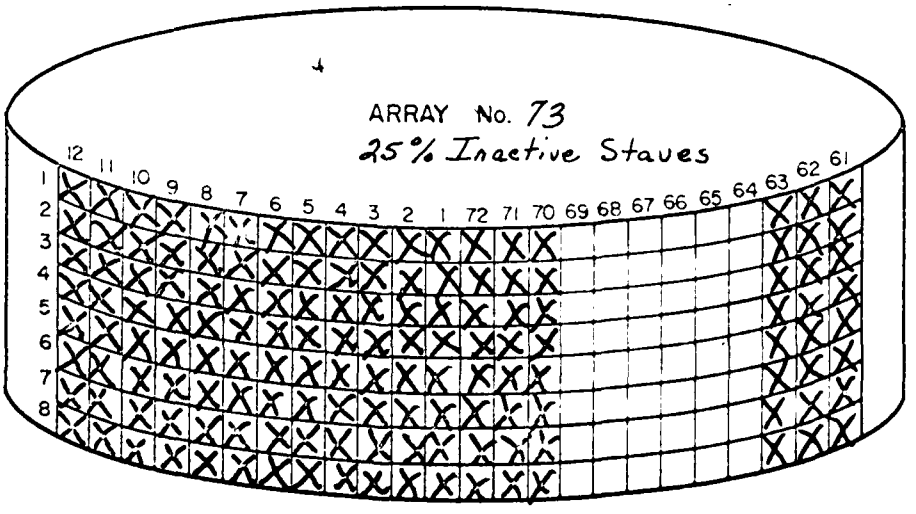
HORIZONTAL RECEIVE BEAM PATTERN
0° TILT ANGLE



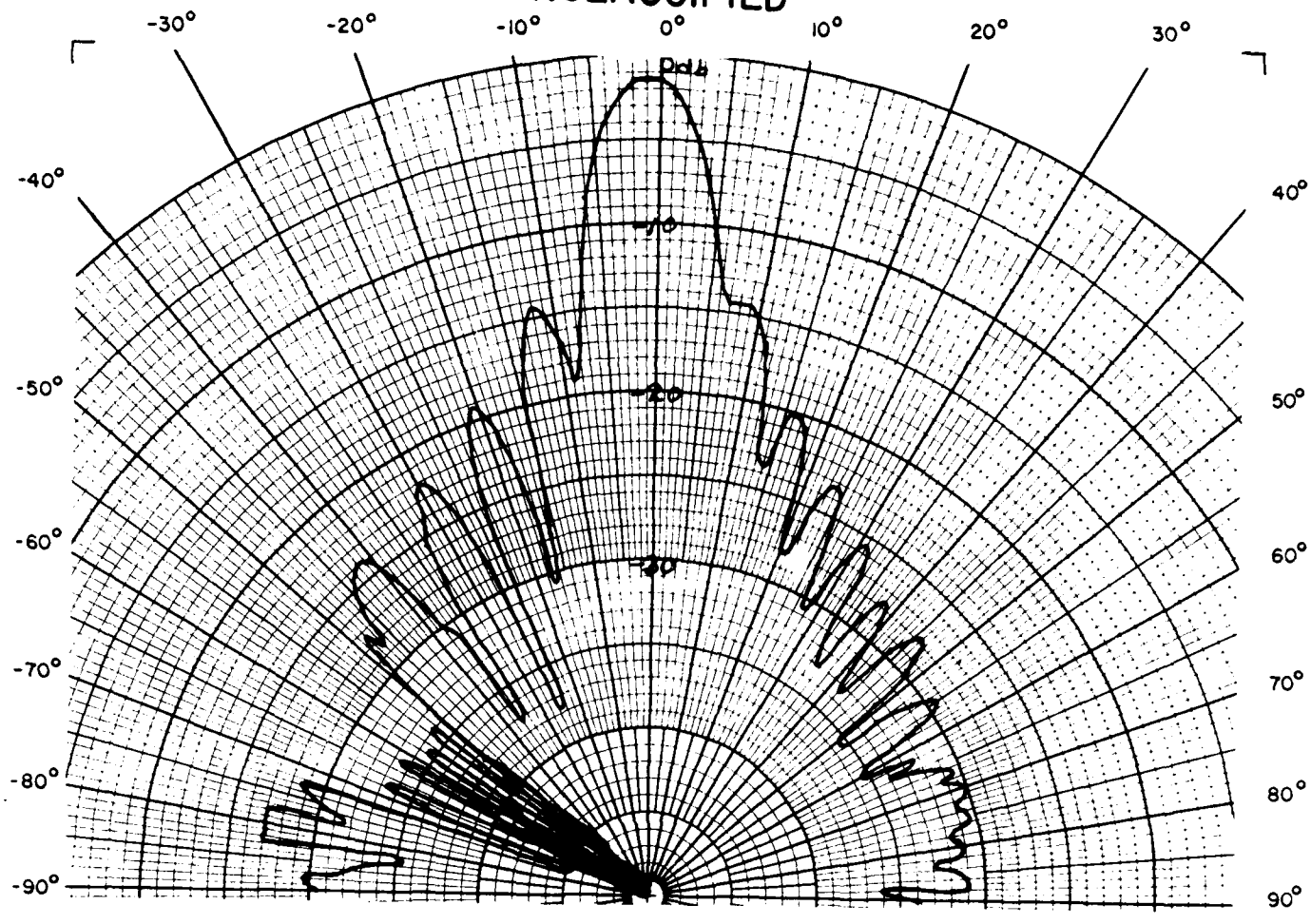
TRACOR, INC AUSTIN, TEXAS DWG A2000-
GTK-JMY-RPD



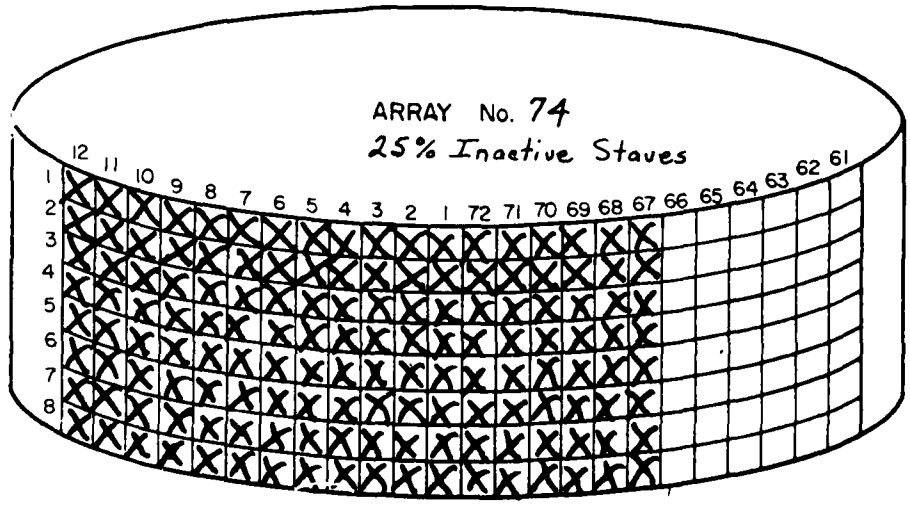
PHASE DIFFERENCE INPUT TO SSI VS BEARING



TRACOR, INC AUSTIN, TEXAS DWG A2000-
GTK-JMY-RPD

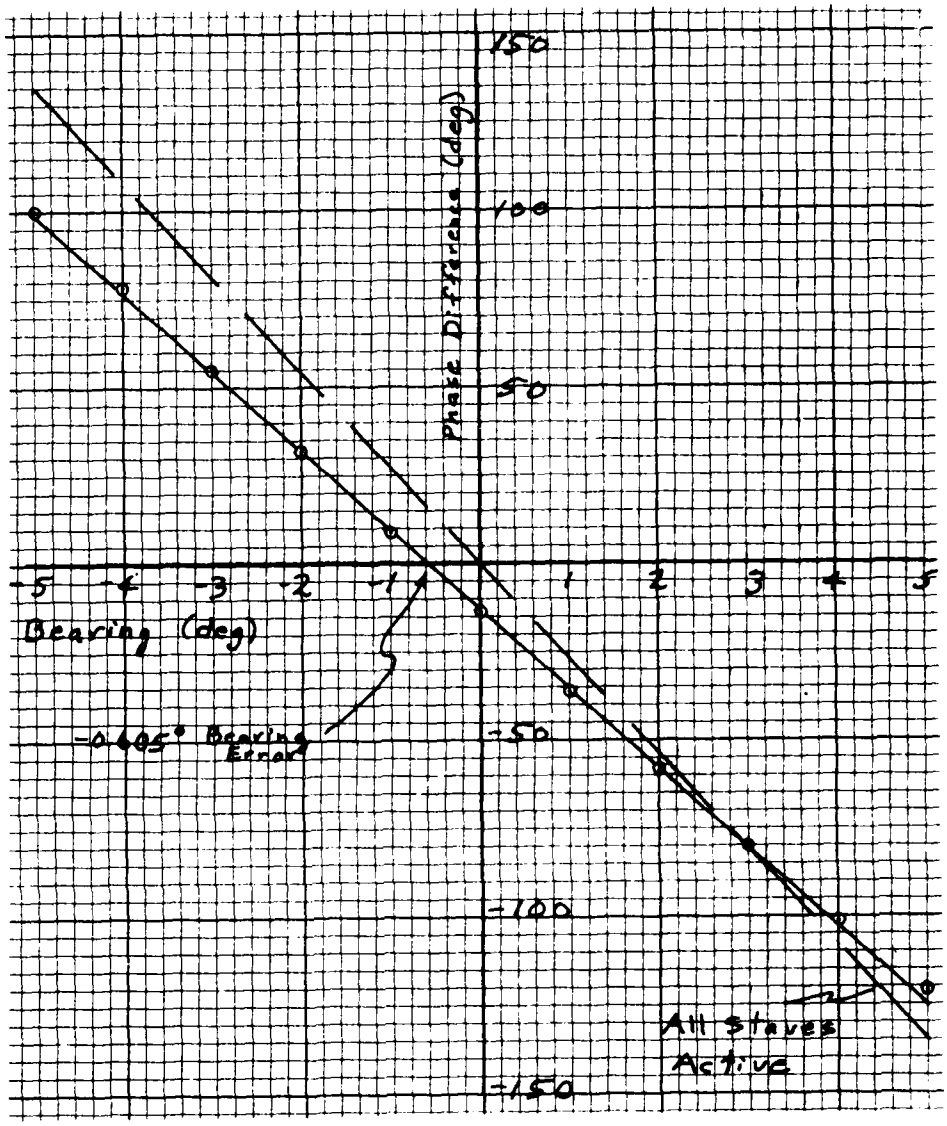


HORIZONTAL RECEIVE BEAM PATTERN
0° TILT ANGLE

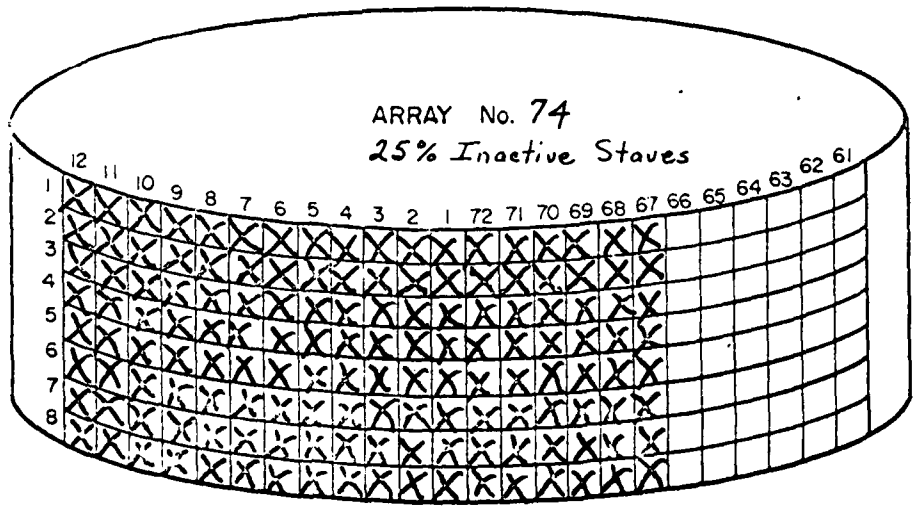


TRACOR, INC
AUSTIN, TEXAS

DWG A2000-
GTK-JMY-RPD



PHASE DIFFERENCE INPUT TO SSI VS BEARING



TRACOR, INC. AUSTIN, TEXAS DWG A2000-
GTK-JMY-RPD